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POWER SYSTEM ASSESSMENT FOR THE
BURNT MOUNTAIN SEISMIC OBSERVATORY

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THOMAS R. LAMP, JR.

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A team of scientists and engineers of the US Air Forces' Wright Laboratory conducted a study of electrical power technologies for use by the Air Force in operating a seismic observatory on Burnt Mountain in the Alaskan Interior. This assessment evaluated a number of proven candidate power generation technologies; including, radioisotope and propane-fueled thermoelectric generators (RTGs and TEGs), engine and wind-driven mechanical generators, chemical storage batteries, fuel cells, photovoltaics, and electrical transmission lines from Fort Yukon to Burnt Mountain. After initial evaluations were completed, the study focused on the most promising technologies, thermoelectric generators (RTGs and TEGs) and photovoltaic generators (PV). Several power systems based on emerging technologies were also evaluated; to include, thermionic, thermal photovoltaic, Stirling, alkali metal thermoelectric converters (AMTEC), and hydrogen thermoelectric converters (HYTEC).

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EXECUTIVE SUMMARY

A team of scientists and engineers of the US Air Forces' Wright Laboratory conducted an assessment of electrical power technologies for use by the Air Force in operating a seismic observatory on Burnt Mountain in the Alaskan Interior. This seismic observatory is critical to verification of nuclear test ban treaties. Because of its remote siting and national security mission the observatory must operate unattended for long periods at a high level of operational reliability. Recent forest fires have raised fears that fire damage to the RTGs could result in radioactive contamination of the Burnt Mountain region.

The evaluation criteria for this assessment included reliability of operation, safety of local residents, wildlife, and Air Force maintenance technicians; and overall life-cycle cost. Selection of the optimum power generation technology is further complicated and heavily driven by the severe operating environment compounded by the remoteness of the location. It is these site-related criteria that drive the selection of a safe and economical power source for Burnt Mountain.

This assessment evaluated a number of proven candidate power generation technologies; including, radioisotope and propane-fueled thermoelectric generators (RTGs and TEGs), engine- and wind-driven mechanical generators, chemical storage batteries, fuel cells, photovoltaics, and electrical transmission lines from Fort Yukon to Burnt Mountain. After initial evaluations were completed, the assessment focused on the most promising technologies: thermoelectric generators (RTGs and TEGs), photovoltaic generators (PV), and a PV/TEG hybrid system. Several emerging technologies were also evaluated for potential application.

The assessment concluded that continued use of the RTGs is clearly the safest, most reliable, and most economical approach to supplying electrical power to the Burnt Mountain Seismic Observatory. The seismic observatory on Burnt Mountain has been safely and economically powered by RTGs since its installation in 1973. They should continue to be operated until the end of their useful power life. The first unit falls below the required power level in 2009. For an added margin of safety it is recommended that combustible materials be cleared annually from the equipment sites.

A logical plan would be to phase out the RTGs as they reach the end of their useful lifetimes. This approach would also provide the opportunity to field test replacement systems without jeopardizing the reliability of the observatory operations. The assessment further concluded that, at this time, propane-fueled TEGs appear to be the best candidate for immediate replacement of the RTGs. However, by the end of the projected useful lifetime of the RTGs other, emerging technologies may prove more economical and safe than the TEGs.

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1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this study is to identify an electrical power source which is suitable for use at remote, inaccessible locations in the Arctic region. The technology must present the lowest possible health and safety risks to both local inhabitants and the technicians involved in installation and servicing. The technology should also produce minimal impact on the local flora and fauna. In addition to the restrictions regarding health, safety, and environmental impact, the candidate technology must possess a life cycle cost which is acceptable to the American taxpayers.

1.2 SCOPE

This study included all power production technologies capable of the power levels required by the application. After determining adequacy of performance, further down selecting was performed based on reliability, environmental issues, and cost. The principal focus of this study was on proven power production technologies. Those power production concepts which were based on emerging technologies did not receive thorough performance and cost analyses.

1.3 BACKGROUND

The United States Air Force has had a long-standing need for power sources capable of operating, unattended, for long periods of time at remote, inaccessible sites. One such application concerns providing electrical power for a remote seismic observatory site on Burnt Mountain in the Alaskan Interior. This seismic observatory is critical for nuclear test ban treaty monitoring. This site is currently powered by strontium-90 "fueled" Radioisotope Thermoelectric Generators (RTGs). Forest fires during the summer of 1992 at the observatory site raised fears of radioactive contamination within the Burnt Mountain area. Local residents surfaced their fears through their elected US Senators, Murkowski and Stevens, who in turn requested that the Air Force conduct an assessment of power production technologies. In December 1992, the Air Force Technical Applications Center (AFTAC) requested that Wright Laboratory (WL) conduct an assessment of electrical power sources appropriate for use at the Burnt Mountain observatory.

The Wright Laboratory team of scientists and engineers evaluated a variety of power systems including radioisotope and propane-fueled thermoelectric generators (RTGs and TEGs), engine- and wind-driven mechanical generators, chemical storage batteries, fuel cells, photovoltaics, and electrical transmission lines from Fort Yukon to Burnt Mountain. There were several emerging power production concepts which were not

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thoroughly evaluated during this study. These emerging technologies have not yet reached a stage of technology readiness which would produce the reliable power systems needed for the Burnt Mountain application. These emerging technologies are briefly addressed in Section 2.6 of this report.

1.4   SITE DESCRIPTION

The Burnt Mountain Seismic Observatory is located in the Yukon River Valley south of the Brooks Mountain Range at 67.42° north latitude and 144.61° west longitude. The two nearest settlements are Arctic Village, approximately 50 miles to the northwest, and Fort Yukon, approximately 56 miles south of the observatory. Fort Yukon is also the principal staging area for Air Force service operations to Burnt Mountain.
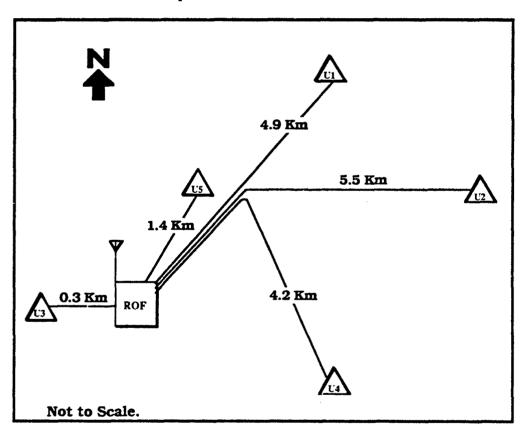
FIGURE 1.4-1 Layout of Burnt Mountain Seismic Observatory Showing Distances Between Sensors

The seismic observatory is made up of five individual sensor sites which are identified as U1, U2, U3, U4 and U5. Each site consists of a borehole for the seismic sensor and a wooden frame shelter for housing two RTGs and associated electronic equipment. For the purpose of data transmission, surface laid cables connect the five Remote Terminals (RTs) to the Remote

Operating Facility (ROF) which is located near site U3. Data from the RT sites is collected at the ROF and transmitted to Ft Yukon via line-of-sight UHF radio. Figure 1.4-1 shows the layout of the Burnt Mountain Seismic Observatory. Figure 1.4-2 is a schematic illustration of site electronics for both the ROF and the five RTs. Security fences surround each equipment shelter and the area around each site is cleared to a diameter of approximately 100 feet. Two additional shelters are located at the ROF near site U3. One serves as lodging for maintenance crews and the second shelters the all terrain service vehicle based at Burnt Mountain.
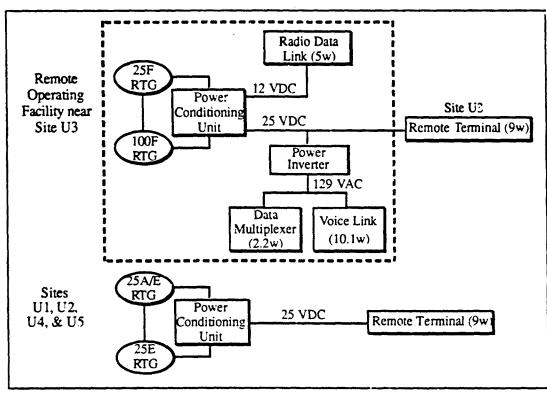
FIGURE 1.4-2 Power Requirements and Distribution Diagram of Equipment for Burnt Mountain Seismic Observatory

The terrain at Burnt Mountain varies from barren rocky ground to areas of considerable overhead and ground cover. Permafrost in the area is discontinuous which requires that detailed soil surveys be performed before embarking on construction projects. The area around the ROF appears to be the most stable and might serve as the best location for installing a central power generator should that arrangement be selected. The elevation at Burnt Mountain is approximately 2000 feet above mean sea level (MSL).

The nearest weather observatory is at Fort Yukon. Typical weather characteristics recorded at Fort Yukon are:

- Temperature   -71°F to +100°F
- Precipitation   17 inches annually
- Wind speed   Average < 5 kts (5.75 MPH), gusts to 35 kts (40 MPH), measured between Jan. 80 and Dec. 89.

1.5   POWER REQUIREMENTS

Table 1.5-1 presents the measured electrical loads for each of the seismic sensor sites (RTs) and the ROF site at the Burnt Mountain Seismic Observatory. If a centrally located power system is used additional power would be required to compensate for transmission line losses. A more complete discussion of the centrally located versus independently located power systems is presented in Section 1.7.

TABLE 1.5-1 Required Power Formats and Measured Loads at the Burnt Mountain Seismic Observatory

Site	Instrument	Format	Load(Watts)
ROF	Data Multiplexer	129 VAC	2.21
ROF	Voice Link	129 VAC	10.11
ROF	Radio Data Link	12 VDC	5.02
U1	Remote Terminal	25 VDC	8.99
U2	Remote Terminal	25 VDC	9.18
U3	Remote Terminal	25 VDC	8.83
U4	Remote Terminal	25 VDC	8.95
U5	Remote Terminal	24 VDC	9.01
TOTAL POWER			**62.30**

1.6   LOGISTICS

The remote location of the Burnt Mountain Seismic Observatory creates unique problems of supply and maintenance for any potential power system which depends on consumable fuels. Surface transportation between Fairbanks and Ft Yukon is best effected by barge up the Yukon River each year after the spring thaw. Surface transportation between Ft Yukon and Burnt Mountain is non-existent. There are no roads and the Arctic tundra is fragile. All supplies and personnel must be flown by rotary wing aircraft (helicopter) into the observatory site.

The extreme environmental conditions and the vagaries of weather also create additional concerns regarding safety and observatory reliability.

All logistical operations into Burnt Mountain must be supported by helicopter. Resources include both US Army and commercial contractors. There is a strong possibility that future US Army helicopter support might not be available as the result of budget reductions; therefore, transportation

support through local contractors might be required. There are no commercial heavy lift helicopters available for cargo operations based in Alaska. Columbia Helicopters, of which Alaska Helicopters is a division, operates Vertol-107 and commercial CH-47D helicopters to support the timber industry in the state of Oregon. The cost of rebasing either of these aircraft to the Fairbanks area was quoted at approximately $90,000. Table 1.6-1 contains the rates and load limits for the type of helicopters which are available at this time.

TABLE 1.6-1 Helicopter Rates and Limits for Military and Commercial Operators in Alaska.

Source	Type	Cost/Hr	Passengers	Cargo(Lbs)
US Army	UH-1	$591	5	1200
"	CH-47D	*$3,490	40	20,000
"	UH-60L	$1,650	12	8000
"	OH-58A	$311	2	100
HeliLift, Inc	206B	$525	3	700
"	206L	$750	4	800
"	212	*$2,285	9	2500
Alaska Helicopters	Vertol-107	*$3,500	12	8,000
"	CH-47D	*$5,620	40	20,000

* Cost per Hour includes fuel (wet).

Fuel will have to be purchased in Fort Yukon or delivered by barge. A Bell 212 is the only heavy lift (up to 2500 lbs of cargo fully fueled) helicopter commercially available in the Fairbanks area. It burns approximately 100 gallons of fuel per hour. The round-trip flight time between Burnt Mountain and Fort Yukon is 1.5 hours and 5 hours between Fairbanks and Ft Yukon. The commercial fuel costs are $3.60 per gallon.

Transportation costs accounted for the majority of all estimated costs associated with the Burnt Mountain logistics operations.

1.7 CENTRAL versus INDEPENDENT POWER SOURCES

For an application such as the Burnt Mountain Seismic Observatory, there are two options for installing the electrical power sources:

    1) Power all sites from a common power source at a convenient, centrally located site.

    2) Equip each site with its own independent power source.

Power generated at a central site would be distributed to the remaining sites by either surface laid or buried cable along the existing cable ways. The power source was assumed to be located at the ROF (near site U3) which contains the data multiplexing and transmission equipment, and is already connected to each of the RT sites by data cable.

For most of the technologies considered, the central power system appeared to be the most effective. Chemical, mechanically driven, and photovoltaics systems appeared to benefit most from a centrally located power source. The minimum size chemical and mechanical power systems produce output power levels (100 to 300 watts) well in excess of that needed to overcome distribution line losses. Some of the RT sites might be shielded from direct sunlight by ridge lines which would reduce the effectiveness of PV systems at those sites. Additional construction in the form of wind turbine towers and solar PV towers is more costly and environmentally disruptive; e.g., three wind turbine towers at a single site is better than three towers at five separate sites.

As a result of transmission line losses, the annual propane requirements for the TEG system is increased by approximately 25%. Independent propane fueled thermoelectric generators at each site is more attractive since the TEG size and power output format is similar to the existing RTGs.

There is also the question of overall mission reliability associated with the central power system. In the case of a failure of a central power source, the entire seismic observatory would be out of operation. With an independent power source for each site, a power system failure would affect only the site in question. It should be noted that the fuel storage facility for any combustion driven device would be vulnerable to forest fires which frequent the Burnt Mountain area.

Resistive losses associated with direct current transmission of power will require that power be converted from low voltage (24V) DC output to high voltage (120 V) DC for more efficient transmission. The DC/DC conversion is on the order of 75% efficient and must be included for both ends of the transmission line. In addition, there are power losses associated with cable impedance.

The transmission line losses for the central power source configuration were calculated and the results are presented in Figure 1.7-1 and Table 1.7-1. Figure 1.7-1 illustrates the trade-off between low voltage DC and high voltage DC transmission of power from a centrally located power source to the remaining sites. The ordinate represents the total power that must be input to the transmission line system (at the ROF) to ensure the requisite power at each RT site. The selection of 10 gauge wire indicates a power input requirement of approximately 66 watts: 36 watts for the four RT sites and 30 watts for line resistance and conversion losses. At a diameter of 0.153 inch, the 10 gauge wire can also be easily handled during installation.

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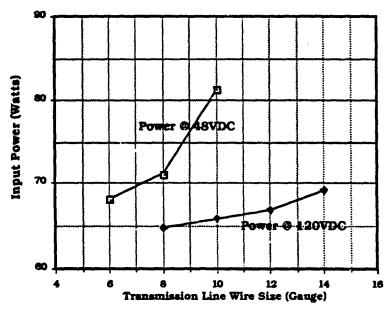
FIGURE 1.7-1 Transmission Line Losses as a Function of DC Voltage and Transmission Line Wire Size. A Central Power Source is Assumed to be Located at the ROF.

Table 1.7-1 contains an estimate for wire material costs and weight associated with installing the power transmission lines. Installation costs are presented in Section 5.0. Figure 1.4-1 was the source of information regarding cable lengths between the ROF site and each of the RT sites. The calculations were based on handbook values for available Mil-Standard electronics equipment. The primary contribution to power loss in the transmission line system is the DC-DC converters whose efficiencies are typically 75%. It is expected that better DC-DC converter efficiencies can be achieved and the input power requirements presented in Figure 1.7-1 are worst case examples.

TABLE 1.7-1 Estimate of Wire Costs and Weights for Power Transmission Lines at Different Wire Gauges.

Wire Gauge	Wire Cost	Wire Dia(In)	Weight (lbs)
6	$62,200	0.257	11,150
8	$36,600	0.218	6,940
10	$28,100	0.153	4,530
12	$15,100	0.122	2,484
14	$11,100	0.105	1,656

2.0 TECHNICAL EVALUATION of CANDIDATE POWER SOURCES

Power generating systems based on several different energy conversion technologies were evaluated for the Burnt Mountain Seismic Observatory; to include, thermoelectric, photovoltaic, chemical, and mechanical. Commercial power from Fort Yukon was also considered as a source of power for the Burnt Mountain observatory.

It was recognized that the Burnt Mountain project could not afford to be ensnared in technical development problems; therefore, only technically sound power systems with field service history were considered as primary candidates. The thermoelectric and photovoltaic systems are the most promising alternatives and the majority of the study effort was focused on these concepts.

It should be noted that the use of any renewable energy source (wind or photovoltaic) would require complete weather surveys at each RT site and the ROF before a more accurate assessment of these technologies could be made.

There are a number of conversion methods that show promise for remote site power sources, but, at this time, are still in the developmental stage. Eventhough these emerging technologies were discounted at the outset of the study, brief descriptions of these power system concepts are presented in Section 2.6.

2.1 THERMOELECTRIC POWER SYSTEMS

Discovery of the thermoelectric effect has permitted the development of small, self-contained electrical power sources. The basic theory, known as the Seebeck effect, states that a voltage is generated when one junction between two dissimilar materials is hotter than the other junction. The voltage is proportional to the temperature difference between the cold and hot junctions of the materials. Any uniformly controlled source of heat can be used to supply energy to a thermoelectric element. Fossil fuels and radioisotope fuels are the most widely used heat sources for terrestrial applications.

Two main classes of thermoelectric semiconductor materials are in common use today, and each has its own temperature limitations. Bismuth tellurides operate in the very restricted temperature range of 0 to 300°C (32 to 572°F) and exhibit device conversion efficiencies of 3 to 5%. Bismuth tellurides are used in fossil-fueled thermoelectric generators. [Teledyne Report, 1971]

Materials based on lead telluride, germanium telluride, silver antimony telluride, tin telluride, and various alloys of these materials operate in the broader range of 0 to 500°C (32 to 782°F) and are more efficient. These

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materials are typically used in radioisotope thermoelectric generators. Conversion efficiencies are typically 5 to 8%. [Teledyne Report, 1971]

In spite of these relatively low conversion efficiencies, thermoelectric generation of electrical power is attractive because it operates without moving parts and can provide relatively stable output over long periods of time.

2.1.1 PROPANE FUELED THERMOELECTRIC GENERATORS (TEGs)

2.1.1.1 Principles of Operation
A thermoelectric generator converts thermal energy to electrical energy. It performs this conversion directly; i.e., no intermediate steps or devices other than the thermoelectric device are required. Combustion thermoelectric generators obtain the necessary thermal energy by the combustion of propane, butane, or natural gas fuel.

2.1.1.2 Background
Experimental investigations conducted at the US Army Electronics Technology and Devices Laboratory, Fort Monmouth, New Jersey, have shown thermoelectric generators to be practical and efficient power sources for military applications. TEGs are being widely used in Antarctica as electrical power sources for a number of unmanned scientific applications where temperatures range between 0°F and -130°F. AFTAC uses thermoelectric generators to provide a portion of the power required for the Alaskan Long Period Array near Fairbanks, Alaska.

Although the combustion thermoelectric generators are off-the-shelf items and are capable of providing the necessary power for the Burnt Mountain area, there are some significant questions regarding fuel supply and storage for these devices.

2.1.1.3 Performance Assessment
This assessment is based on the TELAN thermoelectric generator manufactured by Teledyne-Brown Engineering (formerly Teledyne Energy Systems) of Hunt Valley, Maryland. The attractive and reliable feature of the TELAN system is the heat source which utilizes a catalytic combustor which virtually eliminates problems with "flame-out" at low temperatures.

The TELAN 2T series of generators produce 12, 24, or 48 volts for various conventional uses such as telecommunications, navigational aids, and instrumentation. It is available in 10 watt increments up to 90 watts nominal output.

Combustion thermoelectric devices which meet the Burnt Mountain requirements are not extremely large or bulky. A 10 watt device is approximately 2 cubic feet in volume and weighs 33 lbs. A 40 watt device has a volume of 5.4 cubic feet and weighs 93 lbs.

If a centrally located generator is used, a total of 94 watts would be required because of transmission line losses. The largest TELAN system will generate a maximum of 91 watts at 24 volts; therefore, two TEGs must be used. For this study, it was assumed that a 10 watt and a 90 watt generator would be combined. The combined weight of the TEGs is 126 lbs.

To ensure reliability requirements, a back-up TEG is required. It is also necessary that the devices be equipped with electronic ignition and remote start/stop capability. Systems are available with controller circuitry to monitor line voltages. When the voltage drops below a certain value a relay closes, which triggers a sparker to ignite the back-up generator. Each site will also require a 12V battery for ignition and start/stop capability. Commercially available switching systems have been used as part of hybrid photovoltaic/ combustion TEG systems.

An annual fuel consumption for thermoelectric generators using propane was determined for independently powered sites. Data based on one year of operation at an ambient temperature of 77°F and burner box temperature of 535°F have been used for estimating average fuel consumption. Also a heating value of 19,944 Btu/lb. has been used. Based on manufacturer's data, the fuel consumption would be 12 lbs/week for each of the RT sites and 48 lbs/week for the ROF site. A total annual fuel consumption of 4,992 lbs has been calculated for independent generators at each RT site and the ROF site. This is based on the primary only, not the backup, generator operating at each site.

TABLE 2.1.3-1   Summary of Performance Estimates for Both Central and Independently Sited TEG Power Systems

Electric Power Requirements	Centralized Power Source	Independent Power Sources
ROF and site U3	26 watts	26 watts
RT sites U1, U2, U4, U5	36 watts	36 watts
Transmission Line System Power Losses	30 watts	-0-
TOTAL Power Required	92 watts	62 watts
TEG Power Capacity TEG Propane Consumption	100 watts 6,240 lbs/yr.	74 watts 4,992 lbs/yr.

The annual fuel consumption was found to be higher for the central site configuration. This is because an additional thirty watts of power is necessary to compensate for DC/DC conversion and losses in the power distribution cables. If 10 gauge wire is used, the input power, at the ROF site, would be approximately 66 watts to ensure 9 watts at each RT site (U1, U2, U4, U5). This requires a total annual propane consumption of approximately 6300 lbs or approximately 1300 lbs per year additional fuel to support the central site concept. Table 2.1.3-1 is a summary of performance estimates for a TEG power system.

2.1.1.4   Reliability Factors

Thermoelectric generators are solid-state devices which require minimal maintenance. Teledyne-Brown Engineering quotes a mean-time-between-failure (MTBF) of 34 years for a 20 watt generator and 16 years for a 60 watt generator. Note that these numbers relate to catastrophic failures.

A major concern was the exposure of the thermoelectric generator to the temperature extremes (-71°F to +100°F) characteristic of the Burnt Mountain location. The low temperatures, especially below -40°F, tend to extinguish the combustor flame. During this study, it was discovered that a number of remote site operators are successfully using TEGs at temperatures more severe than those encountered at Burnt Mountain. There are approximately seven sites located on the Antarctic polar plateau at elevations of 6,000 to 11,000 feet. The sites are distributed somewhat uniformly about the South Pole at latitudes between 70° and 86°. Some of the sites have been in operation since 1986.

The site operators indicated that standard flame combustors did experience frequent "flame-out" and that operational experience with TEGs was "miserable". In 1991, the site operators installed TELAN type TEGs with catalytic combustors which are manufactured by Teledyne-Brown Engineering. The experience with these TEGs has been very good. The only problem has been blockage of the combustor fuel jets at low temperatures. The blockage is apparently due to the condensation of the mercaptan fuel additive at low temperatures which then blocks the fuel jets. Mercaptan is added to propane to give it a distinctive odor as a safety precaution. A 10 gallon sump tank installed between the propane fuel tanks and the combustor allows the mercaptan to condense in the sump tank rather than the combustor fuel jets. This arrangement appears to solve the problem. [Doolittle, 1993]

The propane tanks at the Antarctic sites are installed above ground. The tanks are pressurized with nitrogen gas to ensure that propane fuel is always forced to the combustor jets during periods when the temperature falls below -40°F (-40°C). These TEGs operate continuously and waste heat from the TEG is used to ensure that the propane is vaporized before entering the combustor. One potential problem is cold start of a TEG at temperatures less than -40°F (-40°C). This low temperature startup scenario would be typical of the TEG-PV hybrid power system concept. It is possible that the

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temperature could be in the liquid propane range when solar insolation drops to the point where the TEG is required. According to the manufacturer, the TELAN TEG can be configured to switch on at a predetermined temperature, say -30°F, and operate in a standby mode. This would effectively eliminate the problems with -40°F startup. [Doolittle, 1993]

The TEGs should be housed to provide protection from any adverse effects such as corrosion due to rain, ice, and snow. The present shelters used for the RTGs would provide sufficient conditions for the TEGs. If the propane fuel tanks were to be buried at the Burnt Mountain sites, soil surveys must be performed to determine if permafrost stabilization methods would be required for construction of the storage facilities.

2.1.1.5 Safety and Environmental Factors

The principal system risk factor for the TEG is the transportation of the propane fuel. Fuel can only be airlifted in to the site by helicopter. Refueling trips would increase the frequency of helicopter flights into the region with an attendant increase in the risk of serious accident and possible loss of life. The US Army has not reported any serious accidents; however, the increased sorties into Burnt Mountain would increase the risk.

The fragile tundra in the area introduces concerns associated with the size and location of fuel storage tanks, especially if buried. The storage tanks for fossil fuels would be extremely vulnerable to the forest fires that frequent the area. Although there have been no reports of vandalism in the twenty year history of Burnt Mountain operations, current interest could lead to problems. Fortunately the site is remote and difficult to access. The remote location should not impact the maintenance of the combustion thermoelectric devices due to the high reliability of the devices. However, the remoteness of the site does raise safety concerns with respect to helicopter transport of propane fuel.

TEGs are very similar to the existing RTG's, and can use existing shelters. The environmental impact of installing and operating the combustion thermoelectric generators should be negligible. The impact of burying the tanks is not expected to be serious. Due to the remote location and small amount, exhaust products do not represent a threat to health. Potential hazards for TEG installations would be fuel spills and/or fires. Forest fires could also cause serious damage at the site. Although the above problems are serious as applies to the operation of the seismic equipment, the likelihood of occurrence is quite low and any impact on the nearby population would be minimal.

2.1.1.6 Unique Factors

The TEG can be used as the backup power system for a PV power system. The TEG would make up the deficit power during periods of low insolation.

2.1.1.7 Cost

A portion of the first year expenses, including required optional equipment such as electronic ignition, remote start/stop capability, controller circuitry, and a 12 V battery, for the required TEGs at the 5 sites is approximately $68,500. Based on fuel usage with a TEG at each site, it is anticipated that one 500 gallon fuel storage tank should be located at each site with a second tank installed for increased reliability. If a central site is used, it will probably be necessary to install three 1000 gallon tanks. The seemingly large amount of tankage required is due to the low safe fill factor of 75%. Based on material price factors for the Burnt Mountain area, 500 gallon tank prices are approximately $1500. The 1000 gallon tanks are assumed to cost twice as much.

Fuel costs can be broken down into an initial filling cost and the annual refueling costs. The initial fueling cost is higher because there is excess capacity with the combination of tanks selected. The tanks are "topped-off" the first year, then refueled annually on a prescribed schedule. This arrangement provides fuel margin for unexpected refueling problems in future years.

An estimated 30 year life cycle cost for the use of combustion thermoelectric generators at Burnt Mountain has been developed for both the centralized and the distributed TEG alternatives. With any alternative power source chosen for Burnt Mountain operations, there will be significant costs to remove and dispose of the current RTG's along with the cost of additional Environmental Assessment and Impact Studies. Note that the cost of RTG removal has not been included in Table 2.1.7-1.

TABLE 2.1.7-1   Summary of Life Cycle Costs for Propane Driven Thermoelectric Generators. Cost of transport is based on the use of Commercial Bell 212 helicopters.

Cost Element	Central	Distributed
TEG Power System Hardware	49,400	68,500
Initial Fueling Expenses	$89,700	$103,800
Transmission Line Construction	$392,800	0
Propane Tank Installation	$192,100	$180,700
Management/Engineering	$155,700	$75,900
FIRST YEAR EXPENSES	**$879,700**	**$428,900**
Replacements (one time)	**$49,400**	**$68,500**
Annual Cost of Propane	$9,500	$7,500
Annual Cost of Refueling Trips	$22,800	$20,600
Management/Engineering	$6,900	$6,000
29-YR TOTAL OF ANNUAL EXPENSES	**$1,136,800**	**$988,900**
TOTAL LIFE CYCLE COSTS	**$2,065,900**	**$1,486,300**

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2.1.1.8   Summary

Evaluation of propane fueled thermoelectric generators has shown these devices to be a viable power source for use on Burnt Mountain. A strong point of this technology is that devices are mil-spec, off-the-shelf modular components which can be configured to meet power requirements at each of the five sites. Another advantage is that these systems pose no serious health problems for the equipment technicians or any nearby population. The major drawback to the use of this technology is the difficulty, cost, and safety risk associated with refueling at the remote Burnt Mountain location.

2.1.2   RADIOISOTOPE THERMOELECTRIC GENERATORS (RTGs)

2.1.2.1   Principles of Operation

In radioisotope power devices, thermal energy is generated by the natural radioactive decay of a radioisotope. The thermal energy is then converted to electricity by a suitable conversion method. The most widely used conversion method is thermoelectric conversion as discussed in the beginning of Section 2.1.
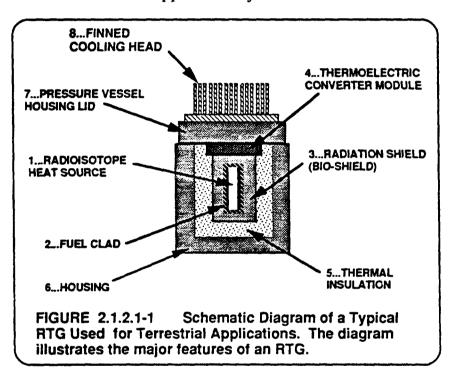
The are approximately 1300 radioisotopes of which only about eight are useful fuels for RTGs. Isotopes are divided into two groups consisting of Type 1 and Type 2. Type 1 isotope fuels are β-emitters and are prepared from spent fission reactor fuels. Type 2 isotope fuels are α-emitters and are prepared by neutron irradiation in fission reactors. Type 1 fuels generally produce lower power densities, but are lower in cost than Type 2 fuels. They also present a greater hazard of X-ray and γ-ray radiation and must be more carefully encapsulated in suitable shielding material.

Strontium-90 is one of the most widely used β-emitters. In its fuel material form, strontium titanate ($SrTiO_3$) was selected because of its fire resistance (1910°C or 3470°F melting point), shock resistance, and low solubility in water. The low solubility is an important feature in keeping strontium out of biological systems.

A description of the RTG's principle components which are illustrated in Figure 2.1.2.1-1 is contained in the following paragraphs.

1...The **Radioisotope Heat Source** used as the heat source for these RTGs is strontium-90 fabricated as strontium titanate.

2...**Fuel Cladding** or **Capsule** consists of a stainless steel liner and nickel base superalloy (Hastelloy C) which encases the fuel. Stainless steels melt at about 1450°C (2640°F) and Hastelloys exhibit melting temperatures of approximately 1350°C (2460°F).

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3...**Radiation Shield (Biological Shield).** This component is fabricated from tungsten (melting point of 3415°C or 6179°F) and provides the majority of the RTG's radiation shielding. This shield, in combination with the RTG's outer housing, reduces radiation levels to less than 10 mR/hr at one meter distance from the RTG's surface. As a way of calibrating this radiation level, a typical chest x-ray is 45 mR and smoking one cigarette is 7.5 mR. Standing one meter from the surface of an RTG for four hours is equivalent to one chest x-ray. One and one-half hours of exposure to an RTG is equivalent to smoking two cigarettes.

4...**Thermoelectric Converter Module.** This element of the RTG converts heat generated by decay of the radioisotope into electricity. The thermoelectric modules are approximately 5 % efficient.

8...FINNED COOLING HEAD

7...PRESSURE VESSEL HOUSING LID

1...RADIOISOTOPE HEAT SOURCE

2...FUEL CLAD

6...HOUSING

4...THERMOELECTRIC CONVERTER MODULE

3...RADIATION SHIELD (BIO-SHIELD)

5...THERMAL INSULATION

FIGURE 2.1.2.1-1   Schematic Diagram of a Typical RTG Used for Terrestrial Applications. The diagram illustrates the major features of an RTG.

5...**Thermal Insulation** is used between the shield and outer housing to direct heat from the source across the thermoelectric module.

6...**Housing.** This component, along with the cover, provides the outer casing and environmental enclosure for the RTG. The housings for the three models installed at Burnt Mountain are constructed from either cast iron (melting point 1230°C or 2246°F), forged carbon steel (melting point 1147°C or 2097°F) or aluminum (melting point 660°C or 1220°F). The fasteners used to hold the housing and cover together require special tools for assembly. This feature discourages unauthorized disassembly of the RTG power unit.

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7...**The pressure vessel housing cover**, along with the housing, form the pressure containment for all the components in the RTG system. The cover is fabricated from the same material as the housing and is attached to it by bolts.

8...The thermoelectric modules convert only 5% of the heat to electricity; therefore, the remainder of the heat energy is rejected by the **Finned Cooling Head**. Thermal control is passive and not subject to failure because of defective pumps, electronic controls or valves.

Appendix A is the original environmental assessment for the use of RTGs. Additional information regarding the RTGs installed at Burnt Mountain is contained in Appendix B.

2.1.2.2 History

RTGs have demonstrated a long and safe history as power sources for remote, inaccessible sites. Use of RTGs began in 1961 and has continued to the present time. In addition to the 58 RTGs manufactured by Teledyne Brown Engineering for terrestrial applications, there are also 41 RTGs which have been successfully launched into space by the United States between 1961 and 1990. The RTGs used on Burnt Mountain were designed for use by the U.S. Navy. The Air Force acquired them as surplus equipment.

2.1.2.3 Performance Assessment

The presently installed RTGs have already demonstrated that they fulfill all the mission requirements of the Burnt Mountain Seismic Observatory; therefore, there is no necessity for analytically demonstrating the performance capability of this power system. This portion of this assessment will focus instead on describing the RTG design requirements and features.

2.1.2.4 Reliability Factors

Radioisotope-powered thermoelectric generators are especially inviting power sources because of their intrinsic reliability and simplicity. As of March 1992, 45 of the terrestrial RTGs are still operational with no failures or radiation leaks throughout their operational history. The approximate number of failure-free hours accumulated by terrestrial RTGs is slightly less than 9,000,000 hours. The term failure in this context refers to failure of the container for the isotope heat source which is the center of controversy. The first RTG was installed at Burnt Mountain in 1973 and has performed flawlessly throughout its deployment. Nine additional units were installed in 1985 and have continued this unbroken line of safe, reliable operation. It is this demonstrated safety and reliability that supports the continued operation of the RTGs for the Burnt Mountain application.

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2.1.2.5 Safety and Environmental Factors

The ten (10) RTGs are housed in environmental shelters which protect them from weather. Regularly scheduled preventative maintenance and radiation survey trips ensure that the RTG power sources continue to function reliably with no ill effects for environment or personnel. Seismic ground motion data from the observatory is monitored around the clock on a daily basis; consequently, any failures or problems with the power system are known immediately.

RTGs are designed to withstand a number of tests which are formulated to assess safety during normal transport and certain hypothetical accident scenarios. The specific purpose of these tests is to ensure that the RTG would survive exposures to fire, mechanical shock, and thermal shock without damage to its radioactive containment capability. These are requirements applied only to the design of the fuel capsule which is Item 2 shown in Figure 2.1.2.1-1. The bio-shield and external housing provide additional safety margin beyond the fuel capsule requirements. Following each test, the fuel capsule must be leak tested to demonstrate that it does retain its original leak tightness. The tests include:

- Fire...the fuel capsule is heated to 800°C (1472°F) for 30 minutes.
- Impact...Capsule is dropped 9 meters onto a flat, concrete supported steel plate.
- Percussion...the capsule must be struck by a steel billet with impact equivalent to 7 kg falling through a distance of 1 meter.
- Thermal shock...while at its maximum operating temperature, the capsule is plunged into 0°C water and submerged for 10 minutes.
- Pressure test...the capsule is subjected to an external pressure of 14,500 psi.

Further information regarding licensing analyses and tests can be found in Appendix A.

The major concern with continued operation of the RTGs at the Burnt Mountain sites is the potential for release of radioactive material into the environment. The hypothetical scenarios for accidental release of radioactive material include fire, airplane crash on an RTG shelter, earthquake, weather, and vandalism. Release of strontium-90 into the biosystem would have dangerous consequences for animal and human life coming into intimate contact with that material. The question to be answered is: "Are these accident scenarios sufficiently strong to overcome the robustness of the RTG design?"

It is instructive to review each of the potential accident scenarios and contrast them to the robustness of the RTG design. The following paragraphs examine how the RTG design tends to neutralize the effect of accidents.

• Fire...the fuel clad is designed and tested to endure 800°C (1472°F) for a minimum of thirty minutes. Additional protection is afforded by the RTG housing which is a metal container capable of withstanding hydrostatic pressures of at least 500 psi. Additional protection is afforded by the thermal insulation (Item 5 in Figure 2.1.2.1-1) which is designed to direct the radioisotope generated heat across the thermoelectric modules. This insulating material would also insulate the interior of the RTG from an external heat source; i.e., fire. RTG fuel claddings have been tested at 1850°F for 2 hours with no signs failure.

• Earthquake...the fuel clad is designed to withstand a drop of nine meters (30 ft) onto a concrete supported steel plate. Additional protection is afforded by the RTG housing which provides hydrostatic pressure containment to at least 500 psi. In the event of an earthquake, the worst case situation would be the collapse of the wooden shelter which might allow the RTG to fall a distance of no more than one meter (3 ft) onto a frozen earthen surface.

• Vandalism...the weight of the RTGs would impede the act of theft. The RTGs are locked within a structure and each site is enclosed by a chain link fence to preclude inadvertent entry. The massive weight (1300 to 4000 lbs) of the RTGs would require heavy equipment for their removal; however, a determined vandal could gain access to the RTGs and attempt removal of the RTG cover lid. An inner lid is designed with special fasteners which inhibit unauthorized removal of the fuel capsule. It should be mentioned that strontium-90 is not weapons grade material and would not be a target for theft.

• Weather induced degradation...the deep sea housing design and type of site installations effectively delete this scenario as a viable failure mode. The original environmental impact assessment (Appendix A) determined that at least three hundred years of direct exposure to sea water would be required to reduce the RTG housing and fuel clads sufficiently to release strontium-90. By then the radiation level would have dropped by a factor of 1000 (approximately 10 half lives).

2.1.2.6 Cost
Initial costs of acquisition and installation have already been borne. There are no refueling costs and the required annual radiation safety surveys are accomplished in conjunction with routine electronics preventative maintenance activities and thus constitute no direct cost intrinsic to the RTGs. Clearing operations around the RTG sites that are intended to reduce the chance of fire damage are more applicable to fossil fuel driven power systems. The only cost that is totally intrinsic to operation of the RTGs is the annual licensing fee which is required by the Nuclear Regulatory Commission. This fee presently amounts to $1,500 per annum. The 30 year life cycle cost of operating the RTGs is:

(30 years)($1,500/year) = **$45,000**

2.1.2.7   Summary

Any device or system which uses radioactive materials must, by law, be designed to meet strict safety standards which were established to protect public safety. These safety standards have been set up by the U.S. Nuclear Regulatory Commission and the U.S. Department of Transportation, and address both the operation and transportation of radioactive devices and materials. The design, manufacture and transportation of RTGs fall into the radioactive device category and, therefore, must comply with these standards. These safety standards are enforced through a series of qualification tests and analyses which include severe transportation accident scenarios, as well as the normal operation and handling of these devices.

The RTGs that are presently in operation at Burnt Mountain comply with all the established safety standards. Throughout the thirty year operational history, the radiation containment ability of a Teledyne RTG has never been known to fail. Any failure in this regard must, by law, be reported. The compliance with the national standards along with the proven safety record and the robust design of RTGs clearly illustrates that continued operation of the RTGs at Burnt Mountain presents no threat to life or the environment.

2.2 PHOTOVOLTAIC (PV) POWER SYSTEMS

2.2.1 PRINCIPLES OF OPERATION

Photovoltaic power systems produce electrical power by converting radiant energy directly to electric energy. Two sources of electromagnetic energy that have been considered for powering this type of converter are: 1) infrared (thermal) radiation at about 15,000 to 16,000 angstroms; and 2) sunlight (solar radiation). This evaluation of PV power systems concentrates on the latter (sunlight) energy source as one of the candidates for the Burnt Mountain Seismic Observatory. A power system utilizing the former energy source, thermal radiation, is an emerging technology and not yet suitable for the Burnt Mountain application. Thermal PV (TPV) systems are briefly described in Section 2.6.

A PV cell is essentially a semiconductor which generates a potential when the cell's p-n junction is exposed to electromagnetic radiation. Typical cells are grown from silicon and from gallium arsenide in crystalline form. Efficiency, as measured by electrical energy output as a fraction of solar energy input, is in the range of 20-30% for monocrystalline cells and 15-20% for polycrystalline cells. Less expensive cells, such as copper indium diselenide and cadmium telluride, have efficiencies in the range of 3-15%.

A p-n junction is obtained when two layers of pure silicon are doped and joined. The p-layer is made by doping silicon with a material such as boron creating a deficiency of electrons (commonly referred to as "holes"). When pure silicon is doped with phosphorus or arsenic, there will be an excess of electrons which leads to an n-type (negative) material. When the two materials are joined, concentration gradients tend to cause electrons and holes to diffuse in opposite directions. This diffusion creates an electric field pointing from the n-region to the p-region.

When the cell is exposed to solar radiation, hole/electron pairs are created on both sides of the junction. This charge separation produces an electric field opposite to the field created by diffusion. When suitable connections from the n and p materials are made through an external circuit, these electron and hole movements constitute a current, which can deliver power. These PV cells constitute the building block of the PV power system.

2.2.2 BACKGROUND

Photovoltaic array power systems have been in operation since the early 1960's. The cost of installing such systems is well documented and information concerning the reliability of such systems in different parts of the world is available. Polysilicon solar cells, the common choice for large solar arrays, are not recommended for this site due to the large "footprint" required, and thus the large supporting structure. Single crystal silicon solar cells are recommended. The silicon solar cells themselves are very reliable, however the reliability of panels and systems for field use can vary

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widely depending upon the selection of the manufacturer and the locality in which the PV system is installed. Most PV systems are installed in moderate climates where sunshine (insolation) is available each day of the year and where the cost per watt is within a factor of ten of that offered by the electrical power company. Solar array installations, not including the batteries required during periods when the sun is not shining, are designed to last at least twenty years.

2.2.3 PERFORMANCE ASSESSMENT

This portion of the study evaluated the use of a photovoltaic array with electrical storage (battery) as an alternate method of providing electrical power during periods of low insolation. The Burnt Mountain Seismic Observatory is located at latitude 67.42°N and longitude 144.61°W.

This performance assessment assumes that the PV power system will be located at the ROF site and that power transmission lines will supply the requisite power to the RT sites. The ROF has good southern exposure and the soil at that location appears suitable for supporting the solar towers. However, before any final commitments for the PV system location is made, a complete site survey must be performed; to include, soil samples and measurement of annual insolation.

Solar arrays must be mounted above the ground and tilted toward the sun for optimum results. At this particular site, the low angle of the sun, even during the best months of the year, will require that the array be mounted perpendicular to the ground. The large surface area normally associated with solar arrays for terrestrial use will require substantial structural mounting to handle the occasional 35 kt wind gusts.

The batteries should be housed in a building or put in battery boxes at the base of each of the solar array towers to minimize the chance of freezing. The design criteria for the battery system is that it shall not exceed a 20% depth of discharge and that the battery efficiency is 80%. A combination of shallow depth of discharge and thermal control ensures that the lead acid batteries will not freeze.

2.2.3.1 Solar Array Calculations
The Burnt Mountain site never receives the amount of solar insolation found at more southern latitudes; therefore, the array must to be significantly larger than those designed for more sunny latitudes. The array was designed using measured output of PV modules presently in use at other locations in Alaska. Insolation data from the Bettles, AK site was chosen because its latitude more closely matches that of the Burnt Mountain Seismic Observatory. [Delaney, 1993]

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Figure 2.2.3.1-1 shows the output of the PV array which was designed for the Burnt Mountain application. The array output is represented by the solid bars and the seismic equipment loads are represented by the cross-hatched bars. The equipment loads in this figure include the transmission line losses between the ROF and the RT sites.
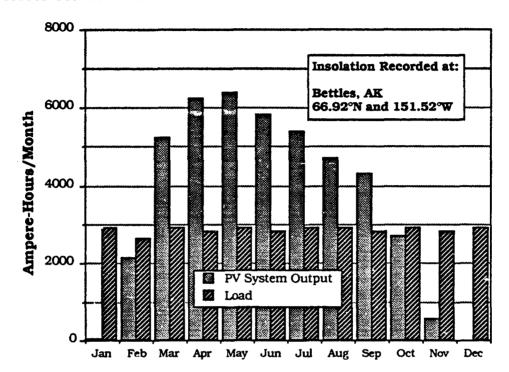
FIGURE 2.2.3.1-1 PV Power System Output Based on Measured PV Module Performance.

The PV array was sized to handle the entire seismic observatory load, and compensate for the distribution line and battery losses. The battery losses were assumed to be equally distributed between charge and discharge cycles. The surplus power supplied by the array over a seven month period is adequate to charge the batteries and compensate for transmission line and battery charging losses. The array provides no useful power during the months of December and January.

The output power shown in Figure 2.2.3.1-1 is based on data supplied for a PV module which can generate 8,680 ampere-hours (Ah) per year at 24 VDC. A module is composed of four solar-cell panels each measuring 48 inches X 21 inches. The four panels in the array module are arranged, electrically, as two panels in series by two panels in parallel (2S x 2P). One module can be mounted on a single tower as illustrated by the example in Figure 2.2.3.1-2.
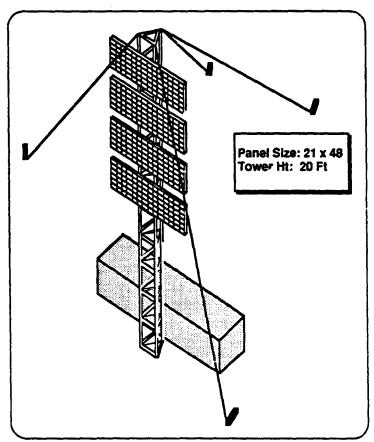
FIGURE 2.2.3.1-2 PV Array for the Burnt Mountain Seismic Observatory.

From Table 1.5-1 and Figure 1.7-1, the total load for the seismic observatory is estimated at 92 watts at 24 VDC, assuming 10-gauge wire for the transmission line. This estimate is broken down as 62 watts for the observatory equipment and 30 watts for distribution line losses. Annual consumption is approximately 34,000 Ah; i.e., 92 Ah/day times 365 days. The module output of 8,680 Ah/yr indicates that slightly less than 4 modules are required to handle the equipment and distribution line losses. However, there is insufficient margin with four modules to cover the 20% battery losses; therefore, a fifth module must be added.

The weight of the arrays is 12.8 lbs per panel times 20 panels equals 256 lbs. If four panels are mounted per tower, then there will be 5 towers and tower bases. The estimated weight of each of the towers is 200 lbs, therefore the tower weights total to 1,000 lbs. The estimated weight of five insulated plywood battery boxes is 1,500 lbs. Guy wires, stakes, conductors and other miscellaneous hardware is estimated to be about 200 lbs. The total estimated array weight is:

Panels	256 lbs
Towers	1,000 lbs
Battery Boxes	1,500 lbs
Misc.	200 lbs
TOTAL	2,956 lbs

2.2.3.2 Battery Calculations

A PV power system, by definition, depends on sunlight for the production of electrical power; which means that a backup power source must be available during darkness or during periods when insolation is too low to generate the power to meet demands. The commonly used method of backup is storage (secondary) batteries. Although there are various types of storage batteries available, lead acid batteries are the most widely used. This is primarily because of their high energy density, reasonable cost, and technological maturity.

The factors that drive the size of the battery storage system are power density (watt-hrs/lb or Wh/lb), depth of discharge and efficiency. The freeze-point of a typical, fully charged lead-acid battery is approximately -80 F (-60 C). As the battery is discharged the freeze-point increases. At a 60% depth of discharge, the freeze-point is approximately 0 F (-18 C); therefore, in cold climates it is necessary to sacrifice useful battery charge to reduce the possibility of freezing. Lead-acid batteries also consume energy during charging and discharging cycles. Typically, this loss is on the order of 20% with most of the loss occurring during the charging cycle.

Lead-acid batteries are usually designed for only ten years of life. The life might be shorter depending on both the number of charge and discharge cycles and the depth of discharge of the batteries. Life cycle costs for large battery systems, such as proposed in this study, could increase significantly if the batteries require replacement more frequently than every ten years.

There are other rechargeable storage batteries which have excellent low temperature performance and long, maintenance-free life; however, this convenience comes at a higher price. The leading low maintenance type of battery is the nickel-cadmium (NiCd) which is several times the cost of a lead-acid battery system, especially when considering the charging electronics and the battery status charge level indicator requirements. A recently developed aircraft quality NiCd battery costs approximately $8.30/Watt-hr; however, it must be noted that NiCd batteries have a much lower depth of discharge than lead-acid batteries. This deeper depth of discharge means that, compared to lead-acid, fewer storage batteries are required with NiCd batteries. Typical commercial NiCds would cost on the order of one-forth to one-third the cost of aircraft quality NiCd batteries.

The size of the battery system can be determined from Figure 2.2.3.1-1. There are approximately seven months throughout the year when the power output of solar array design exceeds the power demand of the observatory.

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It is this excess that must be stored to allow uninterrupted service of the seismic observatory during periods of low insolation. An estimate of the storage system size can be determined by the difference between total annual array output and total annual observatory demand.

Total Annual Array Output	43,400 Amp-hrs
Total Annual Load	33,900 Amp-hrs
Excess Output to be Stored	9,500 Amp-hrs

The assumed depth of discharge is only 20%; therefore, the battery storage is five times the amount of energy to be used from the batteries: 9,500 Ah/0.2 = 47,500 Ah. To size the battery system, the amp-hours must be converted to watt-hours; i.e., 47,500 Ah x 24 VDC is 1,140,000 watt-hours. The figure of merit for battery performance is usually stated in watt-hours per pound (Wh/lb) of battery. The weight of the batteries is based upon the average weight of large batteries i.e.; batteries with storage capacity greater than 1000 Ah. A figure of merit for an aircraft quality sealed lead-acid (SLA) battery is approximately 15 Wh/lb and about 9 Wh/lb for the typical industrial quality battery. Depending on the quality of battery selected, the battery system weight for the Burnt Mountain application can be between 76,000 pounds and 126,000 pounds. The average figure of merit of 12 Wh/lb was used which indicates a battery weight of approximately 95,000 pounds. The figure of merit of 12 Wh/lb is also typical of lead-calcium battery technology which is also used as a backup for PV power systems.

Power to be Stored	47,500 Ah x 24 VDC = 1,140,000 Wh
Battery Weight Required	1,140,000 Wh/12 Wh/lb = 95,000 lbs

About 342,000 Wh of storage capacity, at 80% depth of discharge, would be required if NiCd batteries were used instead of the lead-acid. At 12.0 Wh/lb, this is 28,500 pounds of NiCd batteries. [Swiss, Oct 1993]

2.2.4 RELIABILITY FACTORS

The solar array, battery combination would function unattended in the temperature extremes and during severe weather such as snow storms and high wind. The fact that there are no moving parts and no vibration, significantly reduces the probability of catastrophic failure due to system fatigue. Due to the low sun angle, the array must be carefully located to prevent shadowing by surrounding structures, terrain and vegetation. The bottom of the solar panels would have to be at least four to six feet above the ground. This would minimize the potential for damage by animals and also help eliminate shadowing which could contribute to a reduction in the efficiency of the panels. Additionally it would eliminate coverage by snow drifts.

2.2.5   SAFETY AND ENVIRONMENTAL FACTORS

The array, because of its large surface area, would require extra deep footers and bracing to stabilize the PV towers during gusting wind conditions. The batteries should be housed in an insulated, heated container. The battery container should be on or below the ground to minimize convection losses. A below ground battery installation may disrupt the continuity of the permafrost due to the heat required to keep the batteries operational. Solar arrays are considered to be an "attractive nuisance" and as such attract animals and humans alike. This attraction can result in damage to the system as a result of vandalism or natural curiosity. Solar cell cracking and other nominal system degradation will not have a substantial effect on the total output power of the array.

The major safety issue associated with the PV power system installation is electric shock. The array voltage will be below 40 volts DC so that there will be no problem with electrocuting humans or animals. The main voltage requirement is for 24 VDC, therefore the recommended charging voltage from the array to the batteries is 30 VDC. The transmission line voltage is expected to be on the order of 120 VDC and would constitute the most serious electric hazard at the installation. Burying the transmission cable would resolve this safety issue. Housing the lead-acid batteries may require that they are vented so that there would not be an accumulation of hydrogen gas which would cause an explosion. Forest fires could destroy the array if care was not taken to clear trees and underbrush away. Lead could also be released into the environment if the battery boxes were consumed during a fire.

2.2.6   UNIQUE FACTORS

The unique factor of the PV power system is that it is a renewable energy source which, when used with rechargeable batteries, requires no fossil-fuel for power production. However, a PV system will require regular, planned maintenance of both the PV array and the battery storage system.

2.2.7   COST

The solar array lifetime is estimated to be twenty years. The batteries will have to be replaced after ten years and the power conditioner also within 10 years. The arrays will have to be free of snow cover and ice. They can be protected from hail damage and since the solar panels will essentially be vertical, this type of damage should be minimal. If batteries are housed at the base of each major vertical support for the array, the weight should prove useful in providing permanent mooring in the permafrost.

2.2.7.1   PV System Hardware

The cost of the PV modules used in the array design is $368/module. The normal rule of thumb is that the support structure cost equals the array cost.

The cost of SLA batteries varies from $.05 to $2.00 per Wh. Using $0.10/Wh, the cost estimate for battery storage is $114,000. This cost estimate reflects the use of a deep discharge marine battery and represents a low cost option. The cost of $0.10/Wh is consistent with the cost of PbCa type batteries which are also used to support PV systems.

In reality, the battery system installed for the Burnt Mountain observatory will have to be "tailored" for the application. The electrolyte stoichiometry must be carefully controlled to ensure optimum performance for the expected temperature extremes at the site. This additional development effort is expected to cost approximately $50,000.

The existing shelter should be adequate to house the batteries; however, the use of battery boxes at the base of each tower appears to be warranted. Based on facilities costs at Eielson AFB, the estimated cost of each battery box is $3,425.

Hardware costs associated with the PV system are...

PV Module Costs (20 x $368/module)	$7,360
Support Structure (2 x $7,360)	$14,720
Batteries	$114,000 (NiCd~$250,000)
Battery development	$50,000
Battery boxes (5 x $3,425)	$17,125
Total costs for PV system hardware	**$203,205**

2.2.7.2   Transportation Costs for PV System Hardware

Transportation expenses for moving the PV power system hardware to the Burnt Mountain site include:

> Airlift for PV system hardware
> Daily airlift of work crews at one round-trip per day
> Helicopter Staging expenses
> Food/lodging for helicopter crews

The cost of airlifting this hardware to the site is high. The Vertol V-107 helicopter has over three times the load capacity of the Bell 212; however, when the rebasing cost ($90,000) of the Vertol 107 is included, transportation with the Bell 212 is less expensive. It is possible that transport of the battery system could be couple with use of the CH-47 which must be used to airlift heavy construction equipment to the site. The weight of hardware which must be transported to Burnt Mountain is

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PV System Hardware	2,956 lbs
SLA Batteries	95,000 lbs
Total	~98,000 lbs

No single item exceeds the lift capacity of the Bell 212; therefore, the transport can be divided into 2500 pound loads.

$$98,000 \text{ lbs}/2500 \text{ lbs per trip} = 40 \text{ trips}$$

It is assumed that Ft Yukon will be the staging area for construction of the PV installation at Burnt Mountain. The round trip flight time from Ft Yukon to Burnt Mountain is 1.5 hours. The rate for a Bell 212, including fuel, is $2285/hr.

$$(40 \text{ trips})(1.5 \text{ hrs/trip})(\$2285/\text{hr}) = \$137,100$$

Federal Aviation Regulations (FARs) limit pilot duty to 8 hours of flying time per day. This limits the number round trip flights to five per day. Eight days are required to complete the airlift of all hardware to Burnt Mountain, which also means that 8 round trips must be planned for work crew transport. The cost of overnight stays were based on the government per diem rate for Alaska which is $166/day per person.

$$(\$166/\text{day}) (8 \text{ days}) = \$1,328$$
$$(\$2285/\text{hr}) (1.5 \text{ hrs/trip}) (8 \text{ trips}) = \$27,420$$

The total costs must also include the staging expense of moving the Bell helicopter from the Fairbanks area to Ft Yukon. This round trip flight time between Fairbanks and Ft Yukon is 5 hours.

$$(\$2285/\text{hr}) (5 \text{ hrs/trip}) (1 \text{ trip}) = \$11,425$$

Total expense associated with transport of the PV system hardware is...

Hardware transport	$137,100
Crew food and lodging	$1,300
Work crew transport	$27,400
Staging expense	$11,400
Total Hardware Transport Costs	**$177,200**

2.2.7.3 Site Construction Costs

The Air Civil Engineering unit at Eielson AFB was consulted regarding construction estimates for the Burnt Mountain Seismic Observatory. Site construction expenses include:

Installing power distribution lines from the ROF to the RT sites
Installation of PV array towers

Estimates for installing the power distribution lines were based on 1993 figures for Alaskan labor and equipment rentals. Trenches for laying the power lines were assumed to be 8 inches wide and 12 inches deep with backfill compaction. The trenching would be accomplished with two motor driven trenchers operating at a rate of 1000 linear feet per day per trencher.

The powered trenchers each weigh 4800 lbs which exceeds the Bell 212 lift capability; therefore, the cost of trenching must include the expense of rebasing a commercial CH-47 helicopter from Oregon to Ft Yukon. The CH-47 was chosen (instead of the Vertol 107) because the excavator needed for the PV tower installation weighs 15,200 lbs; therefore, the CH-47 can be used to transport both the excavator and the two trenchers.

Total cost for installing the power distribution lines...

Trenching	$78,000
Transport	$186,000
Labor (3-man crew)	$14,000
Crew Transport	$64,000
Contingency (@ 15%)	$51,000
Total Cost of Distribution Lines	**$393,000**

It was assumed that the foundations for the PV towers were on bedrock which is just a few inches under tundra. The towers are 20 feet high and are based in concrete footers. It was estimated that a six-man crew would need 16 days to install the PV towers. A small tracked excavator is required for installing the towers. The excavator weighs 15,200 lbs and it is assumed that the cost of rebasing a CH-47 helicopter will be shared with transport of the trenchers used for installing the power transmission cables.

Total cost for installing the PV towers...

Clear, excavate and lay concrete footers	$18,300
Small Tracked Excavator Rental	$4,000
Labor for erecting towers	$25,700
Transport (CH-47, 3 trips x 1.5 hrs/trip)	$18,000
Total Costs of PV Towers	**$66,000**

The total estimated initial cost is shown in Table 2.2.7-1. These expenses include all costs determined as necessary to perform initial installation of the PV arrays and their associated battery storage systems. The management and engineering costs are based on 21.5% of all other costs. The basis for this management expense is discussed further in Section 5.

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TABLE 2.2.7-1 Estimated First Year Expenses for a PV Power System Installed at the Burnt Mountain Seismic Observatory.

Cost Element	Cost
PV System Hardware	$203,200
Airlift of PV System Hardware	$177,200
Installation of Power Lines	$393,000
Installation of Towers	$66,000
Management/Engineering	$180,500
TOTAL Estimated Cost	**$1,019,900**

The cost for the PV power system was also estimated for the 30 year life cycle of the system. This estimate was based on periodic replacement costs of PV arrays and battery storage systems. The summary of these expenses are detailed in Table 2.2.7-2.

TABLE 2.2.7-2 Estimated 30-Year Life Cycle Cost for PV Power System

Cost Element	Cost
First Year Installation Expenses	**$1,019,900**
Solar array system replacement (One time)	$7,400
Battery cost for two replacements	$228,000
Airlift Costs, batteries, two times	$173,000
Airlift Costs, replacement Solar Array	$15,000
Airlift Support	$34,200
Management/Engineering	$98,400
Total Equipment Replacement Costs	**$556,000**
Estimated cost of Annual Maintenance Trips	$14,900
Management/Engineering Support	$3,200
Total Annual Expenses	**$18,100**
TOTAL Estimated Life Cycle Cost	**$2,100,800**

2.2.8   SUMMARY

The assessment of the photovoltaic array and battery system for use at Burnt Mountain Alaska indicates that it may be a marginally acceptable alternative for the replacement of the RTGs. The area of the solar array is large enough that it could require considerably more site preparation to survive both the gusting winds and the temperature extremes, however, there are other

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existing systems of the type proposed that are operating at other locations in Alaska.

The site will receive sunlight for more than 10 months, although the intensity and duration of the sunlight in the October, November, December, January, and February time frame is low and short lived, making the accurate design of a solar/battery system a difficult choice for this location. Due to the low sun angle, even in the summertime, the array will have to be mounted almost perpendicular to the ground. With peak winds of 35 kts and several square meters of surface area, the anchoring requirements (piles, concrete, guy wires) must be attended to in detail. The array will simultaneously have to provide power to charge the batteries and also provide site power. During the several weeks of total or near total darkness, when the array produces no practical power, the battery system will power the loads by itself.

The site will require about 95,000 pounds of lead-acid batteries which will have to be maintained above an 80 percent charge level and heated to avoid freezing. Using the more expensive NiCd battery system would reduce the battery requirement to about 28,500 pounds but at significantly higher initial cost. However, the reduced transport requirement and advertised lower maintenance for NiCds could make them competitive with lead-acid. [NIFE, 1993]

A PV system could be combined with a TEG power system to produce a hybrid PV/TEG system in which storage batteries would be replaced by the TEG. It is also feasible that some sites (ROF and RT) could be powered by pure PV systems while others are powered with TEGs. The key to using any combination involving solar PV power systems is accurate weather surveys at each RT site and the ROF. [Ashmore, Oct 93]

The arrays will have to be mounted above the ground, like a billboard, in order to protect them from being snow covered and bothered by small animals. The site will require a heated, insulated, battery building or battery boxes to protect the batteries and make battery replacement or maintenance feasible. Reflection from the surface of the snow will increase the efficiency of the array as will the lower operating temperature which is an average of 17°F. Hail, bullets, and windswept debris are the most likely candidates for damaging the array.

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2.3 ELECTROCHEMICAL POWER SYSTEMS

The operation of an electrochemical power system is based on the conversion of chemical energy to electricity. In an electrochemical device, the chemical energy is converted directly and efficiently into low voltage, direct current electrical energy. A principal advantage of such a device is that, theoretically, the conversion process can be carried out isothermally and the limitations imposed by Carnot efficiency do not apply. Basically, there are two categories of electrochemical power sources: batteries and fuel cells.

Aluminum-air primary batteries and hydrogen fuel cells were the principal electrochemical sources considered for powering the Burnt Mountain Seismic Observatory and they are discussed in Sections 2.3.1 and 2.3.2, respectively.

2.3.1 ALUMINUM - AIR BATTERIES

2.3.1.1 Principles of Operation

In a metal-air battery system, a metal is used to form the negative electrode and a gas electrode using oxygen from the forms the positive electrode. Such systems are potentially very flexible. The majority of research effort has been focused on the development of improved high-rate air electrodes with non-noble metal catalysts. The aluminum-air battery appears to be an attractive battery from a weight and performance standpoint. The theoretical energy density of an Al-air battery is about 3,718 Wh/lb. [Angrist, 1976]
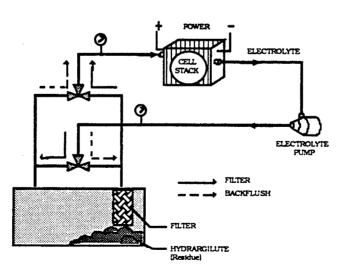
FIGURE 2.3.1.1-1 Conceptual drawing of an Aluminum-Air Battery showing the principal elements of this Electrochemical Power System.

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The aluminum air battery has as its major components an aluminum alloy anode, an oxygen cathode, a caustic (potassium hydroxide) electrolyte, tankage to hold the electrodes and electrolyte plus a small pump to circulate the electrolyte. The principal elements of the aluminum-air battery are illustrated in Figure 2.3.1.1-1. The energy producing electrochemical reaction takes place between metallic aluminum and oxygen which is extracted from the surrounding air through a semipermeable membrane. The voltage produced from a single cell is approximately 1.2 volts and depends on the length of time the cell has been operating.

The circulation pump is required to keep fresh electrolyte in contact with each electrode surface in order to prevent early polarization or voltage drop within the cell. Polarization results from a change in electrolyte composition during the discharge reaction. As the cell discharges, aluminum hydroxide is produced and quickly reaches a solubility limit within the liquid electrolyte. The pump is used to circulate the aluminum hydroxide containing electrolyte through a filter to remove the solid and then return the potassium hydroxide solution to the electrode surfaces to allow further or deeper discharge of the electrodes.

A modular battery design containing twelve 24 volt modules each of which operates for 15 days would be housed within an electrolyte tank. When 15 days have elapsed or when a low voltage limit is detected, the next module would be brought on-line and the previous module shut-down. This switching would occur automatically through a system of sensors, timers and relays. Two batteries are required for one full year of operation.

The aluminum-air battery is mechanically rechargeable. This is accomplished by removing the reacted aluminum anode plates, flushing out the electrolyte and filters and installing new plates and fresh electrolyte. This process is cumbersome and time consuming and it is not recommended that it be performed on-site at Burnt Mountain. Instead it would be more manageable to replace the batteries after the 12 month period and remove and return the used batteries to a maintenance depot to be mechanically recharged and returned 12 months later.

2.3.1.2   History
Aluminum-air batteries typically have been used for stand-by (float service) or emergency power applications. That is the battery is in a reserve configuration until a main power failure requires the use for low alternate power to be supplied. However, for continuous power output applications run-times of up to 1200 hours are projected. Very little data is available to substantiate the projection. The approach suggested by the vendor where twelve modules are used to extend total run-time to meet the Burnt Mountain application is reasonable.

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2.3.1.3   Performance Assessment

The weight and volume of a single dry battery to operate at a central site are 4,778 lbs (2172 kg) and 495 gallons (1872 liters), respectively. To operate for one year continuous at a site two batteries are required. Therefore, total weight and volume (dry batteries) equals 9,556 lbs (4344 kg) and 989 gallons (3744 liters), respectively. In addition, a total of 6,600 lbs (3000 kg) of potassium hydroxide electrolyte is required for battery operation.

It is assumed that after one complete year of operation both discharged batteries will be removed from the site and be replaced with two fully charged batteries. The discharged batteries would be taken to a maintenance depot where they will be mechanically recharged. This involves installation of new aluminum anodes, removal and replacement of spent electrolyte with new electrolyte and system check-out.

For this power system approach, a battery with twelve replaceable modules is baselined. An initial sizing of 300 watts was assumed both to handle the site load and parasitic loads such as module heaters and pump power. Until some detail design work is completed, a more exact power level cannot be determined. This is an important number, for it determines module size. For example, a module sized as described above would weigh 400 lbs (181 kg) which may be too large to handle from a serviceability viewpoint. If so more modules may be required, i.e., shorter run time per module at a reduced power level. Increasing the number of modules increases system complexity with an attendant reduction in reliability. To perform these tradeoffs and the associated development, the vendor has estimated $450,000 would be required. It also estimated the 12-module battery would cost $65,000 per copy thereafter.

2.3.1.4   Reliability Factors

A disadvantage of this system is the need for an electrolyte recirculation pump. In a modularized system, valves have to be incorporated that allow the pump to support whichever module is operating. These valves represent a single point failure mode and may substantially reduce reliability. The single point failure can be overcome with multiple pumps, one per module, but system complexity is increased and serviceability may suffer. In addition, a control system is required to determine when each consecutive module must be brought on line after the previous module is no longer producing at the required power level. The reliability of such a system has not been demonstrated satisfactorily in the environmental extremes expected at Burnt Mountain.

2.3.1.5   Safety and Environmental Factors

The aluminum-air system is attractive because it has no effluents and is thus environmentally friendly. All of the system by products remain within the system and are recyclable. Additionally it has a good reliability record based on telecommunications backup mode experience. How applicable this record is to long term use in the Arctic environment would require a more

detailed design study. This application would represent this technology's first use as a primary power source.

2.3.1.6   Unique Factors
None other than those discussed above.

2.3.1.7   Cost
The unit cost of each 12-module battery is estimated to be $65,000. Recharge costs at the maintenance depot are estimated to be $20,000 per battery. An annual helicopter flight to remove and replace two batteries at a central site is required.   The total weight to be transported annually is 16,156 lbs (7344 kg). The weight includes two batteries at 4,778 lbs (2172 kg) plus two each electrolyte charges at 3,300 lbs (1500 kg).   Due to life limitations of the air cathode, new batteries will need to be purchased after three years of service. In addition the vendor has estimated $450,000 is required for development cost associated with design changes necessary for operation in the Arctic environment and initial life testing. The 30 year life cycle cost (LCC) is summarized in Table 2.3.1.7-1. It is estimated that four batteries will be replaced every six years of service which means five replacements over the thirty year life cycle of the system. Airlift expenses include the cost of staging the helicopter transport from Fairbanks to Ft Yukon.

TABLE 2.3.1.7-1 Estimated Costs of an Aluminum-Air Battery Power System for the Burnt Mountain Seismic Observatory.

Cost Element	Cost
Initial Development	$450,000
Initial Battery Expenses	$130,000
Power Distribution Line Installation	$393,000
Power System Transport	$35,000
Management/Engineering	$217,000
A. Total First Year Expenses	**$1,225,000**
Annual Battery Recharge	$40,000
Annual Airlift Expenses	$35,400
Annual Management/Engineering	$16,200
B. Total Annual Expenses	**$91,600**
C. Life Cycle System Replacements	**$1,300,000**
Total 30-Yr Life Cycle Cost (A+29B+C)	**$5,181,400**

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2.3.1.8 Summary

This battery system was evaluated because it is safer in comparison to high energy density primary battery systems, all by-products are recyclable and it takes advantage of using oxygen from the air as the cathode active material. However, its typical use is in a stand-by mode and not in a continual power output mode of operation. Application to the Burnt Mountain requirement for 12 month operation requires that twenty-four modules at 28 volts (two batteries) be installed to operate sequentially over the 12 month time period. This may be a downfall with respect to reliability.

Although attractive from the standpoint of safety and environmental issues, the aluminum-air battery is not practical for the Burnt Mountain application. The requirement for active pump controls, and module switching leaves many unpleasant questions unanswered concerning the ability to perform unattended through the long Alaskan winters. The lack of field service experience in the role of primary power source is also a strong argument not to select aluminum-air batteries for the Burnt Mountain application.

2.3.2 FUEL CELLS

2.3.2.1 Principles of Operation

The fuel cell concept discussed here produces energy by electrochemically combining hydrogen, which is stored in an external vessel, with oxygen from the surrounding air to produce water as its only discharge product. Oxygen is passively extracted from the air through a semipermeable membrane. The cell operating voltage depends upon design considerations and the current density at which the cell is operating. For the Burnt Mountain application, cell voltage is expected to be approximately 0.9 volts. This translates to a fuel cell stack which contains 35 to 40 bipolar cells to meet the 24 volt DC requirement. Stack operating temperature is in the range of 60 C to 80 C and is maintained by the reaction occurring on the electrodes. Present operating stack designs are able to passively reject waste heat without the use of pumps or fans.

Two options were presented by the vendor to consider for bulk hydrogen storage. Cryogenic storage significantly reduces tank volume and weight but requires a refrigeration system. It is expected to be more costly and less reliable than high pressure gas storage and is not discussed further in this report. High pressure gas storage (5000 psi) requires an external tank, valves and gas lines to deliver hydrogen to the fuel cell stack. Enough hydrogen would be contained to operate the stack for a 12 month period after which a full tank of hydrogen would be brought on-site and the empty tank removed for off-site filling.

It is estimated that 61 gallons (230 liters) of water will be produced over a 12 month period. Water rejection or storage may be a potential problem in

the cold Alaskan environment. Therefore, the vendor has included a development task within the cost estimate to address this area.

2.3.2.2 History

Fuel cells in general have a good history of performance and reliability dating back to early manned space flight missions. However, operational and reliability problems have been encountered when trying to operate a fuel cell stack in reverse, i.e. as a secondary or rechargeable system to produce hydrogen and oxygen for subsequent discharge reactions. Therefore, the fuel cell concept for this study is limited to an energy producing design and not intended to be recharged. This concept requires an external source of hydrogen which would be replaced after the supply is exhausted.

The fuel cell used in this study is based upon work being conducted by the Army. It is rated at 200 watts and is man-portable. This fuel cell, can operate within a range of power levels, e.g. 100 to 300 watts, but at a somewhat lower efficiency. The reduced efficiency within that range is not significant enough to warrant a redesign of the cell. The power output from the fuel cell is controlled by the load and by the flow of hydrogen and oxygen to the reaction zone of the cell. An increase in load and reactant flow to the cell will increase the current density (i.e. amps per square foot) which translates to an increase in power output without changing the physical size of the cell. Of course one cannot continue to increase flow and expect unlimited power output because design limitations would come into play.

The cell could be redesigned to operate at a maximum efficiency for the exact power level required by Burnt Mountain. However, this would incur a substantial development cost. Not much would be gained in that the cell is already at a size which is small enough to be carried by a foot soldier. It is recommended that the developed cell be adapted to the Burnt Mountain application without further cell stack redesign.

2.3.2.3 Performance Assessment

The weights of the fuel cell stack and hydrogen tank are 33 lbs (15 kg) and 1,250 lbs (568 kg), respectively. The volume of the stack is 1 cubic foot (30 liters) and the tank volume is 55 cubic feet (1560 liters). For volume efficiency, the tank could be spherical and have a radius of 28 inches (72 cm.). At the tank design pressure of 5000 psi, approximately 136 kilograms of hydrogen would be available. This is enough hydrogen to power all five sites from a central location for about 12 months. Although one stack is capable of producing power to operate all remote sites it is recommended that a redundant stand-by stack be installed for added reliability. At the present state of development, it is estimated that the stack would be replaced every three years at a unit cost of $300,000. Lifetimes of voltage sensors, pressure sensors and valves required to meter hydrogen to the stack are expected to extend beyond three years and would be replaced on an as needed basis. Their cost is minimal in comparison to stack replacement.

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2.3.2.4   Reliability Factors

The reliability of fuel cells is very good and well proven oftentimes through the use of redundant stacks as proposed in this study. However, the reliability weakness in this preliminary design is focused on the use of hydrogen. Using hydrogen is beneficial with respect to providing a clean, easily controlled flow of fuel to the stack in contrast to other fuels (e.g. methanol, hydrocarbons) whose impurities or by-products tend to limit stack performance. However, feeding the stack from a single tank represents a single point failure mode which reduces reliability. Other design concepts could be developed where multiple tanks would be used but would need to be traded-off against complexity.

Development efforts on fuel cell power systems for military aircraft have been undertaken. This effort was abandoned because of difficulty in maintaining hydrogen tight piping connections over the wide temperatures ranges expected during field deployment. Piping connections tended to leak after repeated temperature cycling. The only truly reliable connections appeared to welded connections.

2.3.2.5   Safety and Environmental Factors

The major safety concern with this proposed technology is associated with storage, handling and transportation of hydrogen. Each year a full tank of hydrogen must be transported by helicopter to the site and exchanged for an empty tank. The empty tank would then be removed to be refilled under controlled conditions. While the hazards of hydrogen are well known and documented, experience shows that changing tanks can be accomplished in a safe manner. To minimize safety hazards, if a leak should occur, the hydrogen tank should be stored external to the structure housing the fuel cell. Since regulations prevent storage underground, a vented outside structure would contain the tank which would also be equipped with hydrogen detectors to issue an alarm when dangerous concentrations are observed.

There are risks associated with transporting hydrogen aboard helicopters. The level of risk is unknown but assumed to be minimal since Department of Transportation regulations permit up to 300 pounds (136 kg) of hydrogen to be transported via cargo aircraft.

2.3.2.6   Unique Factors

None other than those discussed above.

2.3.2.7   Cost

The unit cost of each fuel cell stack is estimated to be $300,000. The annual cost of hydrogen and labor to refill off-site is estimated at $10,000. The annual cost estimate for helicopter flights to transport the 1,250 lb (568 kg) tank is based upon using a Bell 212 helicopter. Due to potential life limitations on the fuel cell stack is estimated that one stack would be replaced every three years at a unit cost of $300,000. In addition, the

vendor has estimated $850,000 is required for development cost associated with design changes necessary for operation in the Arctic environment and initial life testing. Life cycle costs are compiled in Table 2.3.2.7-1.

TABLE 2.3.2.7-1   Summary of Cost Estimates for a Hydrogen Fuel Cell Power System for the Burnt Mountain Seismic Observatory

Cost Element	Cost
Initial Development	$850,000
Fuel Cells	$300,000
Power Distribution Line Installation	$393,000
Management/Engineering	$332,000
A. Total First Year Expenses	**$1,875,000**
Annual Recharge of Fuel Cells	$10,000
Annual Transport Expenses	$14,900
Annual Management/Engineering	$5,400
B. Total Annual Expenses	**$30,300**
C. Life Cycle Fuel Cell Replacements	**$2,700,000**
Total 30-Yr Life Cycle Cost (A+29B+C)	**$5,453,700**

2.3.2.8   Summary

Fuel cell technology is already highly developed and has a very good reliability record for space borne systems. Some development work needs to be performed to address operation in the cold extremes but is not perceived to be insurmountable. Refueling is a simple process but the transportation handling and storage of hydrogen is a major concern. Life cycle costs are quite high but this is not abnormal for this technology since high reliability has been a major driver during its development. From an environmental standpoint the fuel cell produces no effluent other than pure water. However, concerns are once again centered on using hydrogen as a fuel source due to the possibility of a fire.

2.4 MECHANICALLY DRIVEN GENERATORS

Production of power through mechanical conversion methods was evaluated. These concepts included engine driven electrical generators and wind driven electrical generators.

2.4.1 COMBUSTION ENGINE DRIVEN GENERATOR

2.4.1.1 Principles of Operation

By connecting a small (approximately 1 hp) engine to a comparably sized generator it becomes just a matter of redundancy and servicing frequency to make such a system acceptable. Each system will consist of a combustion engine, a gearbox, a lubrication system, a generator, power conditioning equipment, and a fuel tank (see Figure 2.4.1-1).
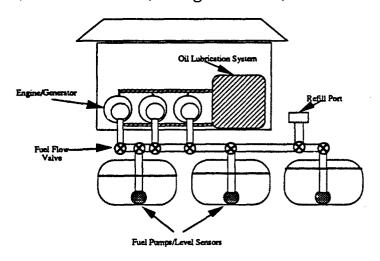
FIGURE 2.4.1-1 Engine Driven Generator System Layout

2.4.1.2 History

The engine that was chosen is a relatively new, low polluting design called the RYOBI Clean Air. This is a 26 cubic centimeter, 4 cycle gasoline engine. A diesel engine was considered, but because of the small power requirements a gasoline approach was chosen. This engine weighs 8 lbs and produces 1 hp at 7500 rpm. Because an off the shelf 1 hp electric generator will run at a lower rotational speed than the engine it is necessary to have a gearbox. The gearbox should be set up to use the same lubrication system as the other rotating components of the system. The gearbox and associated lubrication system weigh about 50 lbs.

Another option is to use a more conventional design engine/generator system where the engine turns approximately 1800 rpm. This rotational speed allows for direct connection between engine and generator and cuts down on system complexity.

2.4.1.3 Performance Assessment

The generator chosen for this effort was a 1 hp asynchronous design and weighs 65 lbs. This machine runs at 1750 rpm and produces 3 phase power at 220 V and 3.1ΛAmps. A power conditioning system would be necessary to convert the AC power to DC.

It was estimated that three fuel tanks of approximately 500 gallon capacity would be required for a centrally located power system. If an engine driven generator system is installed at each site (independent power systems), then three 200 gallon tanks would be needed for each power system. The existing tank used for heating by on-site maintenance crews is a 200 gallon tank. It is estimated, for both siting methods, that two tanks will need to be refilled once per year because of the relatively high (approximately 0.4 lb/hp-hr) specific fuel consumption (sfc) of these internal combustion engines.

The system should have a direct line of site fault detection system with Fort Yukon in order to allow tracking of problems. Fort Yukon should also have the ability to force switch the system to a backup engine/generator loop. Standard sensing arrays to be included are power loss, engine overheat, fuel level and oil pressure loss.

2.4.1.4 Reliability Factors

There will be three systems at each site in order to provide the required redundancy to the site. While one engine is producing electrical power, a second engine will be idling as a !warm backup . The third engine will remain inactive unless one of the other systems has a failure. The current plan is to switch the power usage at the power conditioning system in order to remove the necessity for a complicated mechanically activated backup system switch.

2.4.1.5 Safety and Environmental Factors

As was mentioned in the opening of the engine discussion, this particular design design was chosen because of its environmental improvements over current small engine designs. Below is a table with the RYOBI engine pollutants compared to 1999 California Air Resources Board (CARB) and a two stroke design.

	HC	CO	NO_x
All values in g/hp-hr			
CARB goals	50	130	4
RYOBI	15	127	4
two-stroke	220	515	1

The RYOBI also has the advantages of being quieter and having less vibration than a two-stroke design. Though these are improvements over other combustion engines there may be some effect of the pollutants that such a system produces. The fuel tanks for this system will have to be buried to keep them from freezing, and this may effect the permafrost. There exists

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some chance of incident during fuel transport that would have a large effect on the environment. And finally, the system does present a possibility for a fire or even explosion if under the right circumstances.

2.4.1.7 System Costs

Although a power system based on the engine driven generator was not a strong contender for the Burnt Mountain Seismic Observatory application, an estimate of costs associated with this concept was compiled for both a centrally located power system and independent power systems at the ROF and each RT site (U1,U2,U4,U5). It was assumed that the centrally located power system would be installed at the ROF. Power system installation costs are summarized in Table 2.4.1.7-1 and annual operating expenses are shown in Table 2.4.1.7-2. A description of basic assumptions for estimating expenses is contained in Section 5.0.

First year's (installation) expenses for the engine driven generator power system includes the purchase price of system hardware, fuel, facilities construction and transportation costs.

The costs for the power system hardware includes: the internal combustion engines, electrical generators, lubrication system and gearboxes.

The first year expenses for fuel is the cost of the initial filling of the fuel tanks; i.e., three each 200 gallon tanks for five sites or three each 500 gallon tanks at the ROF, as appropriate, at a safe fill factor of 80%.

Facilities construction has two elements: laying of transmission line cables and burying of the gasoline fuel tanks. The transmission line expenses are unique to the centrally located power systems. The expenses associated with installation of the fuel tanks was compiled with the assistance of personnel from the civil engineering unit (354 CES/CECCM) at Eielson AFB, Alaska. The compact size of the engine driven generator system allows use of the existing shelters; therefore, no additional expenses are necessary for this item.

Transportation costs are the sum of expenses associated with transporting system hardware, power system fuel and construction equipment to the Burnt Mountain area. Trenching operations for the transmission lines and excavating operations for fuel tank installation required the use of heavy equipment. The weight of this equipment exceeds the lift capacity of the Bell 212 and the Vertol 107 helicopters; therefore, this cost element includes rebasing of a commercial CH-47 helicopter from Oregon to Fairbanks, Alaska.

The annual operating expenses are the sum of annual fuel expenses, annual transportation expenses and cost of equipment replacement.

The gasoline fuel consumption was estimated to be 3600 lbs and 10,000 lbs per year for the centrally located and independent power sources, respectively. No single item to be transported exceeds the lift capacity of the Bell 212; therefore, transportation expenses were based on 2500 pound loads per trip. It was assumed that some equipment failures would be experienced each year; therefore, equipment replacement costs were included assuming a 1-in-3 failure rate for the generator power systems.

TABLE 2.4.1.7-1   Summary of Installation Costs for Engine Driven Generator Systems for the Burnt Mountain Seismic Observatory

Cost Element	Central Power System	Independent Power Systems
Engine/Generator System	$4,900	$19,600
Power System Fuel	$2,400	$4,800
Construction	$488,600	$22,900
Transport	$122,700	$195,600
Management/Engineering	$133,000	$52,200
TOTAL	$751,600	$295,100

TABLE 2.4.1.7-2   Summary of Annual Operating Expenses for Engine Driven Generator Systems for the Burnt Mountain Seismic Observatory

Cost Element	Central Power System	Independent Power Systems
Annual Fuel Costs	$1200	$3300
Transport Expenses	$26,000	$52,900
Equipment Replacements	$750	$3900
Management/Engineering	$6,000	$12,900
Total Annual Expenses	**$33,200**	**$69,100**
Equipment Replacements*	$750	$3900

* See Table 5.3-1, Column (1)

2.4.1.8   Summary
The principal factors weighing against the use of engine driven generators is the reliability and cost. Although these systems have been successfully employed in other Arctic sites, those applications required kilowatts of power. Engine driven generators do not have a significant track record for applications requiring tens of watts; which, is one reason for the wide use of RTGs and TEGs in low power applications.

2.4.2   WIND DRIVEN GENERATOR

2.4.2.1   Principles of Operation
Wind driven generators are basically the integration of turbine blade and a reliable generator. Wind velocities provide the energy to turn or rotate the turbine blade which in turn drives the electric generator.

Wind machines come in a variety of shapes and power levels, and can be tailored to almost any application. Wind speeds above 15 mph (13 kts) are generally needed for best use of wind driven generator systems. While there are numerous stations that record average wind velocities, it is prudent to have actual site specific measurements before designing and installing a wind system.   For users in the lower 48 states, small wind power systems (4 kW) for residential use, rated at wind speeds of 25 mph, cost on the order of $2000. A wind driven generator system is illustrated in Figure 2.4.2-1.

DC output variable w/wind

Voltage reg.   Storage Batteries

DC out: Constant voltage
AC out

Resistance heater;
for battery thermal
control

Inverter
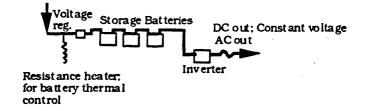
**FIGURE 2.4.2-1   Schematic Diagram of
Wind Driven Generator System**

2.4.2.2   History
Wind driven generators are finding uses in many remote locations where other power sources have previously been used. Small residential wind systems (4 kW) rated for wind speeds of 25 mph (22 kts) have found use in the continental US. Commercial power companies in some western states are beginning to produce megawatt levels of power for their customers. The issue of reliability stills hampers wide spread application of wind generators for commercial power production.

2.4.2.3   Performance Assessment
The efficiency of a wind turbine generator system is around 30%, so this must be factored into the size calculations. Allowing for a scenario in which two of the systems are failed it was decided that each turbine would be sized a little large in order to provide approximately 50% more power than necessary for driving the remote sites. A table for the designs follows.

Turbine output is the total of equipment and battery divided by system efficiency.

	Equipment Power	Battery Storage	Turbine Output	Blade Radius
sites 1,2,4,5	20 W	10 W	100 W	7.5 ft
site 3	50 W	25 W	250 W	12.0 ft
central site	100 W	50 W	500 W	25.0 ft

TABLE 2.4.2-1   Summary of Average Prevailing Wind Conditions at Fort Yukon Alaska for the Period of Jan 80 to Dec 89

Parameter	Jan	Feb	Mar	Apr	May	Jun
Wind Dir (Deg)	02-04	02-04	02-04	02-04	02-04	05-07
Mean Wnd Spd (kts)	3	4	5	6	7	6
Max Wnd Spd (kts)	23	35	29	26	21	27

Parameter	Jul	Aug	Sep	Oct	Nov	Dec	ANN
Wind Dir (Deg)	23-25	23-25	02-04	02-04	02-04	02-04	02-04
Mean Wnd Spd (kts)	6	5	5	5	4	3	5
Max Wnd Spd (kts)	25	30	30	22	25	30	35

Table 2.4.2-1 contains a summary of wind measurements made at Fort Yukon between 1980 and 1990. This accumulation of data clearly shows that wind velocities for this region rarely exceed the minimum recommended levels for efficient operation of a wind driven generator. Basing the wind turbine design on 5 knot wind speeds, the months of December and January are the most likely periods to require battery backup power to meet the power demands of the seismic observatory. Detailed site specific wind measurements are required to more accurately determine the battery requirement and wind turbine design.

For this first-order assessment, the battery mass calculations were based on the two month estimate for backup power, a battery power density of 12 Wh/lb and a 20% depth of discharge. Battery storage system costs were based on a value of $0.10/Wh. The battery design calculations follow. The energy column in the following table is for 2 month battery only operation.

TABLE 2.4.2 Storage Battery Calculations for a Two Month Backup of a Wind Generator Power System.

Description	Power Requirement	Total 2-Month Energy Reqmt	Pb-Acid Storage Battery Reqmt
RT Sites	36 watts	51,800 Wh	21,600 lbs
ROF plus Site U3	26 watts	37,400 Wh	15,600 lbs
Distribution Line Losses	30 watts	95,000 Wh	39,600 lbs
TOTAL	92 watts	184,200 Wh	76,800 lbs

2.4.2.4   Reliability Factors

In order to provide for system redundancy it is estimated that three turbine systems with the excess power used to provide battery charging would be required. This arrangement allows for the failure of one of the generators, while still having a high rate battery charging ability. The rotating machinery will be subjected to low temperatures, freezing moisture and gusting winds. Due to these effects this system is expected to have maintenance requirements on level at least equal with the engine driven generator concept. There is also a concern over the fact that the batteries will need a heated structure to keep them at a reasonable working efficiency.

2.4.2.5   Safety and Environmental Factors

The environmental issues associated with a wind system are mainly due to the battery system and the construction of towers to support the wind turbines. For efficient performance the wind must have undisturbed access to the turbine blades. The rule of thumb is that the platforms be designed to raise the turbine blade tips approximately 30 ft above surrounding wind shields. Wind shields are any structure or terrain feature that obstructs the flow of wind: trees, buildings or ridge lines. This is another aspect that requires detailed site specific information on wind directions as well as wind speeds. This structure may cause problems with the permafrost over a period of time. The size of the tower structure is of greatest concern in the design of a central site system due to the size of the turbine blade. Electrolyte leakage is the most pressing environmental concern associated with the battery backup system.

2.4.2.7   System Costs

The size of the towers needed to support the wind turbine generators raises many questions regarding the feasibility of installing and operating such a power system at Burnt Mountain. Under the prevailing site conditions, it appears that a wind generator system could only be installed in a centrally located configuration; consequently, only costs for that option were estimated. The centrally located wind driven generator power system was assumed to be installed at the ROF near site U3.

The three wind turbine generators for the centrally located power system were estimated to cost $9,810. The cost of storage batteries and the expenses associated with installation of the power distribution lines and the turbine towers was based on estimates for the PV power system. The wind turbine towers were assumed to 50% more expensive than the solar towers.

Recurring expenses were assumed to consist of annual visits to replace failed equipment, cost of annual transport and replacement of storage batteries every 10 years. It was also assumed that annual equipment replacement costs would be equivalent to one wind turbine generator system. It was estimated that tower replacement or repair over the life cycle would be equivalent to the initial cost of one tower installation. Management and engineering expenses were assumed to be 21.5% of all other costs.

First year and recurring cost estimates for the wind driven generator system are contained in Table 2.4.2.7-1.

TABLE 2.4.2.7-1 Summary of Cost Estimates for Wind Driven Generator Power System for the Burnt Mountain Seismic Observatory.

Cost Element	Cost
Power System Hardware Expenses	$28,200
Transport Expenses	$81,000
Power Distribution Line Installation	$393,000
Wind Turbine Tower Installation	$99,000
Management/Engineering	$129,300
A. Total First Year Expenses	**$731,000**
Annual Transport Expenses	$27,000
Annual Equipment Replacement	$9,400
Annual Management/Engineering	$7,800
B. Total Annual Expenses	**$44,200**
C. Life Cycle Battery Replacements	**$55,000**
D. Life Cycle Tower Repair	**$99,000**
Total 30-Yr Life Cycle Cost (A+29B+C+D)	**$2,167,000**

2.4.2.8   Summary

The wind generator was determined to be unsuitable for this application due to poor wind resources and the lack of reliable experience for remote sites. One contractor was interviewed who had experience with wind driven generators. The product was dropped due to miserable experience with wind generators as remote site power sources in the Arctic region. [Delaney, 1993]

The recorded wind data at the Ft Yukon weather observatory indicates that wind resources in that region are marginal at best for wind generating systems. Recommended wind speeds for efficient power generation are above 15 mph. Wind data from Ft Yukon shows averages in the range of 5 mph or less for most of the year. This problem is partially alleviated with the gusting, but still more site specific wind information is required to give a more positive recommendation for wind driven generator power systems.

2.5 "COMMERCIAL" POWER

2.5.1 SUMMARY
The examination of this power distribution method was determined to be impractical for the Burnt Mountain application. From points of view of cost and environmental impact this option appears to be unworkable.

This concept is simply a power cable connecting Burnt Mountain Seismic Observatory to a diesel generator site at Fort Yukon. The straight line distance from Fort Yukon to Burnt Mountain is approximately 55 miles. Installing a power line requires assessment of several factors upon which the ultimate configuration of the power installation will depend. For the distance involved, resistive line losses become a factor, which in turn influences the operating voltage for the line. Typically, one would prefer low voltages because there is reduced problems with safety and reliability. High voltage lines tend to break down more frequently and require greater shielding for safety. But, the higher voltage lines are also more efficient; therefore, the motivation for using higher voltages. The design process for a power line becomes a balancing act between efficiency and safety/reliability as dictated by operating voltage.

The components in the system are readily available, inexpensive and well characteristized. Upon consultation with civil engineering organizations in the Alaskan area, it became readily apparent that the typical engineering parameters, such as efficiency, technology maturity, were not the primary players in this type of installation in the Fort Yukon-Burnt Mountain region. The real engineering challenge for this concept is in managing the installation of the power line through terrain not suitable for civil engineering activities. Additionally, reliability requirements for the seismic observatory would dictate multiple power lines.

There are a number of factors which make the landline a risky enterprise. The window of opportunity for civil construction in this area is only four months, at best. Before a power line could be installed the optional routes between Burnt Mountain and Fort Yukon would require detailed surveying. The purpose of the survey would be to determine the best route, as a function of terrain parameters, such as tundra depth, vegatation, stream fordings, etc. This survey might require as long as four months to complete.

2.5.2 OPTIONS
The options associated with installing an electrical cable are obvious. The cable can be buried underground, it can be suspended from poles or towers, or it can be layed along the surface of the ground. Each of these options has its intrinsic difficulties.

Buried...multiple trenching over the route. Large right-of-ways for trenching equipment which would lead to heavy environmental impact for this fragile ecosystem. The straight line distance is roughly 55 miles; however, the true cable length would be considerably longer than 55 miles.

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This difference, of course, will depend on the route surveys needed to identify obstacles to be circumvented. The estimate for digging trenches to bury the power distribution lines between the ROF and the RT sites was approximately $46,000 per linear mile. Assuming a straightline distance of 55 miles, the trenching expenses from Ft Yukon to Burnt Mountain would be about $2,600,00. This estimate does not include the expenses associated with right-of-way clearing, initial route surveying, environmental impact reports, etc.

Suspended...poles or towers needed to support multiple power lines. Alyeska pipeline experience indicates that thermal stabilization of any supporting structure would have to be undertaken.

Surface layed...this option is probably less mechanically damaging to the cables, but is very vulnerable to damage by wildlife and human vandals. The act of damaging the cable also leaves the perpetrator vulnerable to electric shock. Bears in particular appear to enjoy chewing on cables. There was no data available on this tendency by humans.

2.5.3 FACTORS WEIGHING AGAINST THE COMMERCIAL POWER OPTIONS

Buried Power Line... There are concerns regarding the effect of ground shifting which is characteristic of tundra. Movement of the tundra can subject any buried lines to heavy shear loads which could stress the buried cables to failure. There is justification for these concerns...oil companies are having similar problems with shifting of the Alyeska pipe line and some of the fences surrounding the seismic observatory sites must be "replanted" on occasions. The permafrost pushes the fenceposts out of the ground. Conequently, the land-line concept appears to be of low reliability.

Suspended Power Line... Buried poles or other such supports are difficult to maintain in the tundra environment. A method of permafrost stabilization would have to be employed which would lead to additional costs and possibly reduced reliability.

Surface Layed Power Line...low reliability and a significant danger to wildlife and humans.

High Cost...cost estimates for constructing the power line have varied between $2 million and $8.4 million. The wide range is due to the uncertainity associated with weather and unknown character of the terrain involved. More accurate costs estimates could only be made following a complete route survey. The cost of maintenance is also expected to be high as a result of vulnerability of the power lines to the environment, and wildlife/human activities. For example, detecting failures would require inspecting each foot of cable between Fort Yukon and Burnt Mountain. The four-month window of opportunity applies to power line maintenance as well as construction.

2.6 EMERGING TECHNOLOGIES

In this section other modes of converting heat to electricity are discussed. The methods discussed in this section for one reason or another have not shown as much promise as previously discussed methods. While at present these methods are not well exploited, breakthroughs in materials or techniques could cause one or more of them to come into prominence. Table 2.6-1 compares the conversion efficiency of these emerging technologies and highlights the motivation for developing these technologies.

TABLE 2.6-1 Comparison of Conversion Efficiencies for Various Emerging Technologies.

Technology	Present Efficiency (%)	Future Efficiency (%)
Thermionics	10-15	20-25
Thermal Photovoltaics	15-20	>30
Stirling Converters	20	30
HYTEC	--	30
AMTEC	20	30

A few of these technologies are beginning to receive attention for terrestrial power sources; specifically, Stirling converters and thermionic converters. Researchers at NASA-Lewis Research Center are developing a 100 watt propane heated Stirling converter which has potential for remote site power. This US Stirling converter work is also supplemented by field tests and developmental work in Great Britain. Engineers and scientists at Wright Laboratory are developing thermionic power systems as potential power sources for aircraft and missiles. These thermionic power systems could also be suitable for remote electrical power systems.

2.6.1 COMBUSTION THERMIONIC GENERATORS

A thermionic power generator converts heat to electricity through thermionic emission of electrons from a hot metal surface called the emitter. The electrons are collected on an opposing collector surface and routed through a load back to the emitter which completes the circuit. The primary application has been for space nuclear power systems where the superior power density and high heat rejection temperature makes this conversion technique very attractive for space system applications. Some work was done in the 1970s on thermionic topping cycles for steam power plants and, recently, researchers in Holland and the Former Soviet Union have engineered thermionic power systems which operate off the exhaust gases of domestic water heaters.

The most simple thermionic converter (TIC) consists of two parallel planar electrodes (emitter and collector) separated by a vacuum space. This form of TIC is referred to as a vacuum converter. Because the emitted electrons are charged particles that constitute the working medium of a TIC, they produce a negative space charge in the region between the emitter and collector. Unless neutralized, this accumulation of electron charge will severely reduce the converter performance. Several methods have been proposed and investigated to limit space charge effects; to include, close-spaced converters and plasma converters. The plasma converter is the most successful and widely used method and depends on the introduction of positive ions into the interelectrode space to neutralize the negative space charge.

Cesium vapor is the material of choice as the ionization media for plasma converters. The positive cesium ions provide space charge neutralization and provide the necessary low work function for the collector surface. Figure 2.6.1-1 shows several TIC performance curves for a typical planar converter. The effect of variations in emitter temperature (T_e), cesium vapor temperature (T_{Cs}) and interelectrode spacing (d) is clearly indicated.

In recent years, considerable work has been done on close-spaced converters, both in the U.S. and the Former Soviet Union. In this type of thermionic converter, the emitter and collector electrodes are very closely spaced; e.g., typically less than 0.0005 inch (1.3 x 10^{-3} cm). Close-spaced converters produce reasonable efficiencies at lower temperatures than conventional converters. This makes them suitable for use with low temperature heat sources such as propane combustors and bottoming cycles of steam power plants.

The major **advantages** of thermionic converters are their relatively high efficiency, high power density, and simplicity. Planar thermionic converters are presently undergoing extended performance testing at Wright Laboratory. These units produce efficiencies of 13-15% with a typical output power of about 50 watts. The emitter and collector areas are each 16 square centimeters and operate at temperatures of 1850K and 1000K, respectively. Analysis suggests that advanced converter concepts employing advanced electrode materials, dual vapor ionization and close-spaced electrode designs could push TIC efficiencies to 25-30%.

The major **disadvantage** of TIC power systems is the high operating temperature. In terrestrial applications, the issues of heat loss are more severe as well as the problems associated with high temperature oxidation of materials. Close-spaced TICs have been tested recently at approximately 12% efficiency with electrode temperatures of 1300K and 800K, respectively. However, the 10μm or less electrode spacing presents reliability and manufacturing problems which must be overcome. [Fitzpatrick, et al, 1993]
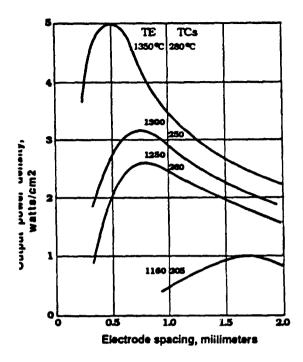
FIGURE 2.6.1-1 The dependence of power output
density on electrode spacing in a low pressure
cesium thermionic converter. [Angrist, p286]

Conclusion. At the present time, the lack of demonstrated field experience in terrestrial applications makes thermionic generators a high risk choice for the Burnt Mountain power systems. Further, higher thermal losses intrinsic to the higher operating temperature may offset the advantage of higher efficiency for a state of the art TIC.

2.6.2 THERMAL PHOTOVOLTAICS

Thermal photovoltaics (TPV) is identical to photovoltaics with the exception that solar radiation is replaced by radiation from a heated body. Such a radiating structure can be tailored to produce energy in a narrow band of the spectra, usually shifted toward the infrared. Several materials have been identified which can produce up to 70% of their radiated energy in a band only 10% wide. As a result a PV material can be bandgap tailored to match the radiated energy spectra and produce electrical energy with improved efficiency. Any heat source can be utilized which produces temperatures of 1000 - 2000 K. The radiative source could be somewhat similar to the carbon mantle in a gas fired coleman lantern.

The principal **advantage** offered by this form of energy conversion is high efficiency. Theoretical studies indicate efficiencies up to 35% are possible. Several emitter experiments have demonstrated a radiating structure:

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however, the efficiencies measured to date have not duplicated the theoretical predictions. The TPV concept is also a static conversion process which offers good reliability for remotely operated power systems.

The principal **disadvantage** of the TPV concept is its extremely low technological maturity. Several technical challenges stand in the way of realizing an operational field system: cell design development, development of cell materials, and reliable emitters. Two sources of loss in the TPV device are reflection and heating. In the former case, reflection losses can be somewhat mitigated by geometrical arrangement of the radiative source and the TPV cells. In the case of heating, it is desirable that the incident spectrum have energies near the energy gap of the semiconductor in order to minimize the excess photon energy. Excess photon energy does not contribute to electrical output of the TPV device but only heats the lattice thus degrading performance. The bottom line is that serious materials developments are needed to provide a solution to these loss problems.

Conclusion. Interest in the TPV concept has grown recently but the device is basically a laboratory curiosity and is unsuitable for the Burnt Mountain application.

2.6.3 COMBUSTION DRIVEN STIRLING CONVERTER

The recently developed free-piston Stirling engine combined with a linear alternator (FPSE/LA) shows great promise as an electrical power source for remote, unattended applications. FPSE/LA was initially developed to be used with radioisotope heat sources for space applications requiring electrical power in the multihundred-watt range. The ability to scale to electrical output power levels in the tens of watts, and to be able to couple FPSE to combustion heat sources, makes it potentially suitable for application such as the Burnt Mountain Seismic Observatory. With typically two moving parts, the FPSE is mechanically simple.

The Stirling engine makes use of the pressure changes brought about by displacing a fixed mass of gas back and forth between a heated region and cooled region. The configuration for one form of Stirling engine is illustrated in Figure 2.6.3-1. This type, called a thermo-mechanical generator (TMG), was developed at the Atomic Energy Research Establishment, Harwell, England. Work on this concept was performed in the 1970s [Cooke-Yarbrough, 1974].

In the TMG, heat is converted into mechanical energy by generating cyclic gas pressure changes at a frequency of about 100 Hz. These pressure changes deflect a thick metal diaphragm which causes a permanent magnet to oscillate between stationary pole pieces. Windings on these pole pieces deliver alternating current. Various versions of the MG were built and tested with combustion, electrical, and isotope heat sources. One isotope heat source was operated for 13 years in the Harwell laboratory. A propane

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heated version provided the primary power source in the UK National Data Buoy, and operated continuously in the Atlantic for 21 months.

FIGURE 2.6.3-1 Basic Arrangement of a
Thermo Mechanical Generator (TMG)
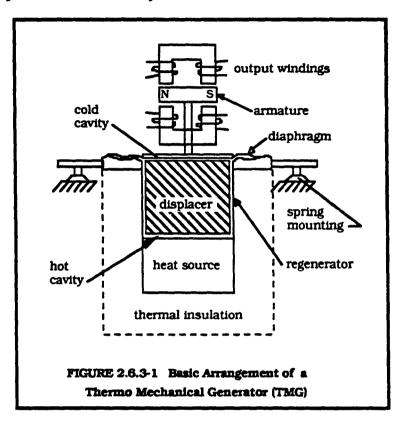
Table 2.6.3-1 contains predicted performance characteristics for a Stirling engine configuration considered for the Burnt Mountain site.

TABLE 2.6.3-1 Predicted Performance Characteristics of a Free-Piston Stirling Engine

Electrical Power	120 Watts
Annual Propane Consumption	1100 lbs
Package Dimensions (meters)	2 L x 1.5 W x 2 ht
Weight	155 lbs

Summary

The Stirling cycle conversion concept possesses some inviting characteristics; which include:

relatively high efficiency 20 to 30%
compact
Stirling can utilize a variety of heat sources
the TMG or FPSE are relatively simple designs.

The experience accumulated by the UK with their TMG program reveals the future promise for Stirling powered remote sites. Of all the emerging (advanced) conversion concepts, the Stirling technology is probably the nearest to actual application. However, despite the attractive features of the Stirling conversion concept, this form of power conversion is, at present, still a developmental test device with little field experience. It is this reason that the Stirling conversion concept was not selected as serious candidate for the Burnt Mountain application.

2.6.4   MICROWAVE POWER BEAMING

Microwave power beaming, in simplest terms, is conversion of electrical energy to microwaves, transmission of the microwave energy to a distant antenna and receiver, and reconversion of the microwave energy back to electrical energy. It was assumed that line of sight (LOS) transmission was possible for the data illustrated in Table 2.6.4-1. These calculations were performed as a "sense check" of the power beaming concept. LOS transmission is presently used to link Burnt Mountain ROF site with Ft Yukon. If the microwave power beaming concept were seriously considered, site surveys would be required to measure beam spread and evaluate potential dangers to human and wildlife.

TABLE 2.6.4-1   Preliminary Analysis of a Microwave Link to Transmit Power from Fort Yukon to Burnt Mountain, AK.

Freq (GHz)	Antenna Size (Ft)	Output Power (Watts)	Input Power (Watts)	Efficiency (%)
2	12	150	1,401,000	0.011
8	12	150	350,000	0.043
12	12	150	233,000	0.064
2	15	150	898,000	0.017
8	15	150	224,000	0.067
12	15	150	149,000	0.100

The **advantages** of the microwave power beaming concept is that the electrical power generator would be at an attended location and that there would be no installed transmission line across the Yukon basin.

The **disadvantages** of this concept are immediately apparent in Table 2.6.4-1. If repeater stations are required then the efficiency goes down even more. Therefore, Table 2.6.4-1 represents a best case scenario. Even more than efficiency considerations, the potential safety hazards to humans and wildlife caused by the intense electromagnetic fields is cause for concern with this concept.

Conclusions. The rationale for rejecting this concept is also one of technical maturity. In addition to the low efficiency, there are other technical issues: reliability of high power microwave devices, clear line of sight path between Ft Yukon and Burnt Mountain, and the safety issues mentioned above.

2.6.5   HYDROGEN THERMOELECTRIC CONVERTER (HYTEC)

HYTEC is a thermally regenerated fuel cell power system utilizing hydrogen and lithium or sodium as the fuel cell reactants. The cell produces electric power by the thermal decomposition of metal hydride and has a high efficiency approaching Carnot. The technical thrust for this concept is for 5 to 10 KW space power systems where the heat source is radioisotope material; however, any combustion fossil fuel source could also be used.

Potential **advantages** of HYTEC are:

> Efficiency several times greater than thermoelectrics or thermionics
> Static...no moving parts but efficiency is approximately that of dynamic cycle conversion (30%)
> High power density device
> Flexibility in operating temperatures & heat sources

The **disadvantages**...several developments needed before HYTEC can be reduced to practice:

> Electrolyte development
> Membrane development
> Measurements of hydrogen transport and partial pressures in liquid metal mixtures

2.6.6   ALKALI METAL THERMOELECTRIC CONVERTER (AMTEC)

AMTEC is a thermally regenerative electrochemical device for the direct conversion of heat to electrical energy with efficiencies approaching Carnot. Studies have projected thermal to electric conversion efficiencies of 15% to 35%. One experiment has demonstrated 19% efficiency and other tests have shown efficiencies of 12 - 13.2% for operating periods up to 1700 hours. The operating temperature range is roughly 900K to 1300K on the hot side, and 400K to 700K on the cold side of the AMTEC device.

Efforts within the past eighteen months have lead to the development of an AMTEC converter that utilizes capillary pumping to recirculate the alkali metal fluid. This development both simplifies and miniaturizes the

converter. Laboratory devices are about one inch in diameter, six inches long and produce 5-6 watts of electrical power. Further success with these devices could result in a very suitable converter for remote power applications. [Hunt, 1993]

The **advantages** advertised for AMTEC are:

> High efficiency, near Carnot theoretical efficiency
> Efficiency greater than 20% in 2 years, 30% in 4 to 5 years
> High power density approximately 20 watts/kg.

The **disadvantages** of AMTEC...Several technical factors of concern need resolution before this concept can reach application.

> Alkali metal inventory control
> Reliable recirculation
> Working fluid purity
> Circulation system durability

3.0 SUMMARY OF RELIABILITY ISSUES

This study addresses performance, reliability, safety, and cost of electrical power production systems. When issues of reliability or safety are addressed in this report, it is the energy sources or energy conversion methods that are being scrutinized. Although reliability of electronics and instrumentation affect performance of the Burnt Mountain Seismic Observatory, it is the intrinsic reliability of the power systems which is the object of the work contained herein.

This section of the report discusses reliability issues associated with only those technologies which were determined to be strong candidates for the Burnt Mountain application; i.e. RTG, TEG, and PV. Reasons for rejecting other power technologies are included in the respective assessment for each technology.

RTGs are attractive power systems where conditions of remoteness or inaccessibility call for a power system which can operate reliably for years without fuel or maintenance. The RTG converts heat to electricity by direct static conversion. The heat source is radioactive decay of the isotope Strontium-90. The static conversion process is thermoelectric. The key feature of the heat source and the conversion process is that they both are direct, static, and passive. This means no moving parts to fail, no active thermal control devices to fail, no active electric generator controls to fail, and no fuel supply to fail or replenish. These characteristics result in a power system of exceptionally high reliability.

RTGs have been in use as space and terrestrial power systems for over thirty years. During that period, approximately 9,000,000 hours of safe and reliable operation have been accumulated with the radioisotope heat source. Teiedyne-Brown Engineering has accumulated over 500 million hours of reliability data to estimate a failure rate of approximately 1×10^{-9} failures per hour per thermocouple element of their thermoelectric conversion modules. Teledyne estimates a mean time between failure (MTBF) of 800 years for their RTGs.

The published MTBF for Teledyne's TELAN thermoelectric generator is 34 years for a 20 watt system and 16 years for a 60 watt system. These MTBFs reflect the lower reliability of the combustion heat source as compared with the radioisotopes used in the RTG. Both systems use thermoelectric conversion modules to convert the heat to electricity. TEGs have demonstrated reliable performance for remote sites in Antarctica as well as Alaska. The downside of TEG reliability would be the timely supply of propane fuel to the observatory site. Also, from a reliability point of view, any power source relying on combustible fuels would not survive a serious forest fire which happened to consum the structures housing the power system. The electronics, in the best case, which provide data processing and transmission would be damaged, and in the worst case combustible fuels and power systems would be completely destroyed.

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The reliability of photovoltaic panels is also good with an expected life of about ten years for a solar array. The lead-acid battery backup for the PV panels, in general, is good; however, the effect of environmental conditions at Burnt Mountain would be difficult to assess at this time. Using the more expensive NiCd battery backup could yield a more reliable PV system if the initial system cost could be tolerated. NiCd batteries are tolerant to both temperature extremes and deep discharging.

The prospect of using a TEG as the backup for a PV system has promise but the added control complexity may make this approach less reliable than the TEG or PV system alone. If this concept is applied, it would be prudent to provide battery backup for at least one month. Some second-hand information was obtained regarding the use of a TEG/PV hybrid system in Alaska. The indication is that considerable difficulty was encountered with startup of the TEG under cold weather conditions. The source of this information was the helicopter contractor that supplied transportation for the service visits to the sites. The Wright Laboratory team was unable to contact a participant in this activity for first-hand information; however, pursuit of the issue is being continued. [Scarborough, 1993]

4.0 SUMMARY OF HEALTH AND SAFETY ISSUES

Any device which employs radioactive materials, even in small amounts, must comply with stringent safety requirements in order to safeguard the public. Minimum criteria must be met not only for normal handling and use, but also under severe accident conditions. Under all circumstances, the fuel must be contained. A more complete description of the tests which verify compliance with these safety requirements was presented in Section 2.1.2.

The history of the Burnt Mountain area indicates that forest fire is the most likely accident scenario to affect the seismic observatory sites. It was the fires on Burnt Mountain in 1992 that raised local fears and drove the need for this power assessment study.

Forest fires represent virtually no risk to the RTG and its radioactive fuel. In order to release the strontium fuel into the environment, fire temperatures in excess of 2400°F (1315°C) would be required to melt the fuel encapsulation. The chemical form of the fuel is strontium titanate, a ceramic type material, which melts at 3470°F (1910°C). The fuel is further encapsulated in a tungsten cylinder which protects the environment from the radiation produced by the natural decay of the strontium fuel. The melting point of the tungsten bio-shield is 3415°C or over 6,100°F.

The RTG shelters are vulnerable to forest fires. According to interviews with Alaskan Fire Service and Dayton, Ohio, Fire Department personnel, the maximum temperatures resulting from a fire involving structures similar to the RTG shelters would be in the range of 1800°F - 2000°F. It was further estimated that the 8 ft x 8 ft x 20 ft structure would be completely consumed in 10 - 15 minutes. This estimate was based on fire department experience with residential garage fires. The conditions and availability of fuel at the sites would not support rapid combustion or what is commonly referred to as a "fire storm". Even a fire which completely consumed the small wooden building in which an RTG is sheltered would not produce the temperatures and duration of combustion necessary to breach the strontium fuel containers.

Should a spill occur at Burnt Mountain, the consequences are very difficult to determine in a meaningful way. The answer will require analysis resources which are beyond the capability (manpower and funds) presently available at Wright Laboratory. However, the suggestion of an answer to this question might be found in Tables II and III of the environmental assessment contained in Appendix A. The low solubility of $SrTiO_3$ in water implies that the contamination would be limited to the immediate area of the spill. The Burnt Mountain Seismic Observatory is monitored around the clock; therefore, the elapsed time between breaching the fuel capsule and the arrival of Air Force personnel would only be within a few days, at most. This rapid response in combination with the low solubility of $SrTiO_3$ would tend to restrict the contamination to a small area.

Transportation appears to be the single largest safety issue for any of the power systems which use consumable fuels. There has been no reported loss of life in flying accidents occurring as the result of US Army helicopter operations in Alaska. If RTGs are replaced by an alternate power system, it would be instructive to know in which way air crew safety would be affected by increased air operations represented by necessary refueling operations. Although this section speaks specifically to air crew safety, it should be understood that, depending on location and circumstances, an accident involving a propane transporting helicopter could pose a threat to both environment and native residents.

A number of Air Force and Army safety offices were consulted regarding a method to quantitatively determine how increased air operations influence air crew safety. The unanimous response was that a quantitative answer depends on a very complex set of variables and meaningful results would require a detailed understanding of climatic conditions as well as accurate definitions operational parameters.

One could form a simplistic model based on data such as that contained in Table 4-1 that assumes accidents are directly proportional to flight hours. This model could produce the expectation of accident over the 30-year life cycle of the power system. However, this simplistic approach ignores any special factors which would drive up the probability of accident, such as, special climatic conditions in the operating region, multi-flights per day, equipment parameters, etc. The role environment plays in accidents is illustrated by U.S. Army accident statistics. The Army-wide rate, over all operations, is 2.66 for 1993; whereas, the accident rate in the State of Alaska was approximately 8. Accident rates are based on 100,000 flight hours. On average, over all operations, the expectation of mishap for CH-47 helicopters is approximately 1.5 in 10 years; while, the expectation for the smaller, less complex, UH-1 is less than one in 10 years. [Hicks, Oct 93]

TABLE 4-1 PRAM Comparisons for FY91-93. Data for US Army Helicopter Accidents Throughout the State of Alaska. Total operations estimated at 20,000 hours annually. [Mysictz, Aug 93]

| FY | Cause of Accidents | | | | | Total | Classification |
	Environmental	Maint.	Human	Mat'l	Unk		
93	7	3	25	33	14	113*	A-0 D-0 B-1 E-77 C-4
92	8	7	14	57	6	92	A-1 D-1 B-0 E-87 C-3
91	6	5	20	59	5	95	A-1 D-3 B-0 E-87 C-5

* extrapolated for balance of FY93 based on data from first 3 quarters

Although Class A accidents are the only ones listed as involving loss of life, when air transport of fossil fuels (propane) is involved, any B-, C- or D-Class accident can constitute a serious hazard to flight crews. These classes of accidents can be *uncontrolled* mishaps and, with propane cylinders on board the aircraft, there is sufficient impact force to create safety hazards to the crew. This fact highlights the serious safety penalties which can be associated with helicopter transport of volatile fuels. [Hicks, Oct 93]

The definition of accident classes are:

- Class A...greater than $1,000,000 in damages, fatality or total destruction of aircraft.

- Class B...$200,000 to $1,000,000 in damages

- Class C...$10,000 to $200,000 in damages

- Class D...$2,000 to $10,000 in damages

- Class E...$2,000 or less in damages.

No loss of life has been reported over the past five years; however, it is logical to assume that increased air operations into the Burnt Mountain area does increase this risk to life.

5.0   LIFE CYCLE COST SUMMARY

The major cost elements of this study are: the cost associated with the removal and long term storage of the RTGs and the life cycle cost estimates for all the candidate power systems.   The cost of eventually removing the RTGs from Burnt Mountain is discussed in Section 6.   This recovery cost must be borne at the end of the useful life of the RTGs and, therefore, is not an element of life cycle costs for candidate power systems.   The cost of long-term storage of the RTGs is however a cost that must be included in the life cycle cost calculations because it must be added to the installation and operational cost of any power technology selected to replace the RTGs.

The first RTG power output will fall below that required by the Air Force equipment in about 15 years. The Air Force expects to have a continued need for data from this observatory beyond 2009 but simply needs to select a power generation scheme for the future. (See Table 5.0-1)

TABLE 5.0-1   Estimated Dates at which RTGs will not Produce Enough Power to Meet Seismic Observatory Demands.

Site	RTG S/Ns	Date
U1	008 & 017	Jun 2018
U2	009 & 020	Jan 2018
U3	001 & 014	Mar 2009
U4	010 & 018	Jun 2019
U5	004 & 019	Aug 2012

5.1   DEFINITION OF RATES AND ASSUMPTIONS USED FOR COST ESTIMATES

The information contained in Table 5.1-1 was supplied by the Air Force cost estimating group (HQ AF CESA/DC) at Tyndall AFB, FL.   The percentage factors are used to estimate the contribution of management and engineering activities to the overall cost of a project.   Management and engineering expenses are estimated as a per centage of the total of other project expenses.   The area cost factor can be used to estimate the cost of goods and services in Alaska from a known cost for the same goods and services in the lower forty-eight states. [Hammond, Aug 93]

TABLE 5.1-1   Cost Factors Used for Calculating Expenses Associated with Candidate Power Systems for the Burnt Mountain Seismic Observatory.

Type of Factor	Value
Management, Supervision & Overhead	6.5%
Continguency	5.0%
Engineering, Design	10.0%
Total Management/Engineering Factor	**21.5%**
Area Cost Factor for Alaska	**2.18x**

Assumptions for estimating operational expenses for the candidate power systems for the Burnt Mountain Seismic Observatory are:

- Bell 212 can carry 300 gallons (1270 lbs) of propane per trip. The propane is contained in 6 each 50 gallon tanks which are mounted inside the aircraft. This method is presently employed to supply propane to TEG powered sites in Alaska. [Scarborough, 1993]

- Ft Yukon is the staging area for service operations to Burnt Mountain.

- Trip times:
  - ✓ Round trip, Ft Yukon to Burnt Mountain is 1.5 hours
  - ✓ Round trip, Fairbanks to Ft Yukon is 5 hours

- Staging expenses are those expenses associated with moving the helicopters and crews to the staging area and may include the following costs:
  - ✓ 5 hours round trip flight time between Fairbanks and Ft Yukon.
  - ✓ per diem at $166/day per crew member for multi-day flight operations.

- Flight crews are limited to 8 flying hours per workday in accordance with Federal Aviation Regulations.

5.2   DISPOSITION OF THE RTGS

The Waste Management Division of DOE was contacted for guidance in preparing the disposal procedures and disposal cost estimates for the ten RTGs. Information specific to the ten RTGs installed at Burnt Mountain was supplied to DOE to aid their review. The following paragraphs are a summary of the contributions received from DOE. [Guercia, Aug 93]

The information regarding the Burnt Mountain RTGs indicates that this waste is class C material, as defined by 10 CFR 61 (Code of Federal Regulations). While DOE statutorily is not required to follow 10 CFR 61 requirements for DOE waste, DOE Order 5820.2A forbids the *disposal* of waste exceeding class C requirements at DOE facilities. However, DOE may accept class C waste material for *storage*.

Prior to acceptance of the RTGs by any DOE facility, AFTAC must petition the Office of Waste Operations (EM-32), Office of Environmental Restoration and Waste Management at DOE-HQ. The petition should provide basic information regarding the RTGs, including:

- Any agreements by AEC, ERDA, or DOE to accept the RTGs for disposal. These agreements would show that the RTGs are or are not "DOE waste".

- Copies of the appropriate Certificates of Compliance

- Engineering details of containers and RTG construction

- Activity of the strontium within the RTGs

The appropriate storage facility would be determined by EM-32 based on the petition. With the information contained in the petition, the storage facility would determine heat generation characteristics and necessary long term storage configuration. AFTAC would be required to provide funds necessary to upgrade the storage facility's Safety Analysis Report (SAR) to allow storage of the waste. The necessity for an upgrade of SARs would not be known until the petition had been reviewed by the selected storage facility. [Guercia, Aug 93]

AFTAC would be required to submit documentation and waste requests in accordance with the storage site's waste acceptance criteria. The waste acceptance criteria are very detailed, and no estimate of the costs of the characterization effort could be provided.

The eventual cost of storage for the RTGs would be:

- Storage fees

- Special rigging fees

- Extra costs incurred by the storage facility associated with management of waste streams

- Safety analysis associated with the waste stream

Assuming that the Hanford site were selected as the storage site, the annual storage rate would be $168.68/cubic foot for FY93. This rate will escalate

annually. For the ten Burnt Mountain RTGs, this annual storage fee is $18,465. DOE sources indicated that escalation rates run approximately twice the annual inflation rate. Assuming a modest 3.5% annual inflation rate, the annual fee escalation is approximately 7%. At this 7% escalation rate, the total life cycle storage cost for the ten RTGs is approximately $1,866,000 over a 30 year period. [Guercia, Aug 93]

DOE experience with Navy RTGs indicates that the AFTAC RTGs will probably not need special riggings, additional waste stream management costs or additional safety analysis reports. [Guercia, Aug 93]

5.3 LIFE CYCLE COST OF CANDIDATE POWER SOURCES

The life cycle cost estimates for the various candidate power systems were compiled from hardware manufacturers and service suppliers. Standard US Air Force pricing factors were applied as addressed in Section 5.1. The cost estimates for new facilities at the Burnt Mountain site was generated with the help of the Air Force Civil Engineering organization at Eielson AFB, Alaska. [Danowski, Aug 93]

TABLE 5.3-1   Summary of Life Cycle Costs for Candidate Power Systems (No Escalation Applied)

Type of System	(1) System Replacements	First Year System Expenses	(3) Annual Opnl Cost	(4) Total 30 Year Cost
TEG	$68,500	$428,900	$34,100	$1,486,300
RTG	0	0	$1,500	$37,500*
PV (Solar)	$556,000	$1,019,900	$18,100	$2,100,800
Battery	$1,300,000	$1,225,000	$91,600	$5,181,400
Fuel Cell	$2,700,000	$1,875,000	$30,300	$5,453,700
Engine DG	$22,000	$751,600	$33,200	$1,736,400
Wind DG	$154,000	$731,000	$44,200	$2,167,000
Commercial Power		$8,000,000	$30,900	$8,896,000
Clearing Opns			$59,300	$1,779,000
RTG Storage			$18,500	$462,500*

* Maximum cost for storage and fees for full 25 years but can vary depending on removal of RTGs from service.

No escalation for inflation is contained in Table 5.3-1 that summarizes the costs associated with each candidate power system. The purpose of this table is to compare the expenses in 1993 dollars. Assuming a modest 3.5% annual inflation rate, the escalated life cycle costs (LCC) can be estimated by multiplying the annual operational cost (column 3) by 51 and adding the result to the costs contained in columns (1) and (2). The factor of 51

represents 29 years of operation. For example, the escalated LCC for TEGs is (51 x $34,000) + $69,000 + $429,000 or approximately $2,237,000. The escalated cost of RTG storage depends on a 7% inflation rate and the escalation factor would be approximately 68 over the 25-year period.

If immediate removal of the RTGs is mandated, then the Air Force must bear the unscheduled cost of RTG storage plus the potential additional cost of installing a less than optimum replacement power system.

Figure 5.3-1 is a visual illustration of two basic options for addressing RTG removal from Burnt Mountain. Option 1 represents the continued operation of the RTGs until the end of their useful life. Option 2 represents the case in which immediate removal of the RTGs is mandated. In either option, a replacement power system must be brought on line. Option 2 has the added expense associated with disposal/storage of the RTGs since useful power is being thrown away.

The real cost issue is how soon the RTGs must be replaced. From the point of view of immediate replacement, the TEG is the most logical choice. TEGs are available and they have a reasonable performance history in cold climate operations. PV systems are the most desirable replacement, but uncertainties regarding site specific solar insolation must be resolved. Should independent siting of PV systems prove possible (as a result of site surveys), then the cost is significantly reduced and a PV system becomes more promising.

Battery storage is another issue relating to PV power systems. Recent input from AFTAC's Technical Operations Division (TOD) regarding the operating costs associated with NiCd and lead-acid batteries indicates that the LCC for lead-acid is about 50% greater than for NiCd. TOD's information is based on experince at a site in Korea where both types of batteries were used. [Brosseau, Dec 93]

Cost issues, as well as issues of safety and reliability, appear to favor continued operation of the RTGs to end of their useful power life.
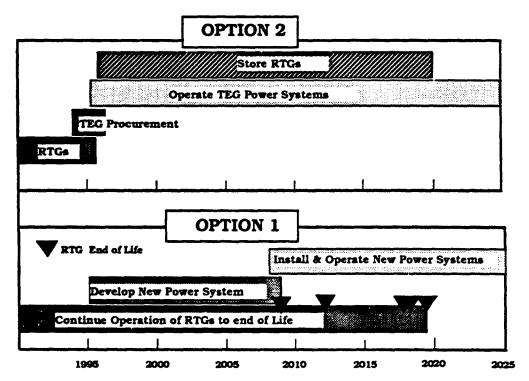
FIGURE 5.3-1 Visual Illustration of Two Basic Options for Replacement of the Burnt Mountain RTGs.

6.0 COST OF RECOVERING RTGs

6.1 TRANSPORTATION

The scenario used for transporting the RTGs from Burnt Mountain site to a storage/disposal facility was the reverse of transporting the RTGs to the site. The personnel involved in that action were contacted and a complete itenerary was reconstructed. The Department of Energy (DOE) facility at Richland, Washington was assumed to be the final destination for storage or disposal of the RTGs. The transportation scenario is summarized as follows. [McAlister, Apr 93]

- Burnt Mountain to Ft Yukon by CH-47D helicopter...5 round trips for RTGs plus one round trip for an all terrain forklift

- Ft Yukon to Eielson AFB, AK by C-130 cargo aircraft...2 trips

- Eielson AFB, AK to MCClellan AFB, CA by C-141 cargo aircraft...1 trip

- McClellan AFB, CA to Richland, WA by commercial truck...2 trucks [Metler, Aug 93]

TABLE 6.1.-1...Summary of RTG Transportation Costs from Burnt Mountain, Alaska to Richland, Washington.

Transport Mode	Cost
Helicopter, CH-47D	$33,700
Air Transport, C-130	$60,000
Air Transport, C-141	$50,000
Surface Commercial Transport	$2,500
Management/Engineering	$31,400
TOTAL	$177,600

6.2 ENVIRONMENTAL IMPACT ASSESSMENT

The National Environmental Policy Act of 1969 requires a detailed statement assessing the impact of any action which could significantly affect the quality of the human environment. The transport of RTGs can be interpreted as an action which could "significantly affect the human environment" and, as such, would require an environmental impact assessment. A point to consider is: If the decision to conduct an assessment is a close call, it is probably better to prepare the assessment rather than ensnaring the project in litigation over the necessity of an environmental impact assessment.

In the case of transporting the Burnt Mountain RTGs, an environmental impact assessment will probably be required. The cost of such an assessment was quoted to range between $20,000 and $100,000. The final cost would be a function of the number of review cycles involved. Contacts with DOE quoted $50,000 as a reasonable estimate of the environmental impact assessment. [Guercia, Aug 93]

6.3 SUMMARY OF RTG RECOVERY COSTS

The total cost of recovering the RTGs from Burnt Mountain are summarized in Table 6.3-1. As seen with other cost calculation in this study, transportation represents the single-most expense cost element.

TABLE 6.3-1 Summary of Costs to Remove RTGs

Action	Cost
Transport of RTGs	$177,600
Environmental Assessment	$50,000
Safety Analysis Reports	-0-
First-Year Storage Fee (FY93)	$18,500
Management/Engineering	$47,000
TOTAL	$293,100

7.0 CONCLUSIONS

It has been concluded that operation of the Burnt Mountain RTGs to the end of their useful lifetimes will represent no unreasonable threat to the environment. Several factors weigh in favor of this conclusion:

- The demonstrated, long-term, successful operation of these particular power units.

- The robust design of these RTGs makes them especially hardy in terms of any potential hazards or accidents at Burnt Mountain.

- Transporting the RTGs from Burnt Mountain is intrinsically higher risk than continued *in situ* operation.

It was further concluded that the TEG power system is the most viable alternative should immediate replacement of the RTGs be mandated. Factors weighing in favor of this conclusion are:

- Proven reliability of TEGs in Arctic and Antarctic environments.

- Reasonable initial costs.

- Easy interchangability with the present RTG system.

- Availability.

An ideal solution to the Burnt Mountain Seismic Observatory power issue is a power system such as photovoltaic-battery which relies on a renewable energy source. The need for a battery storage system can be alleviated by using a hybrid PV-TEG system in which the battery storage is supplanted by the TEG. There are at present two factors which weigh against the selection of the PV-battery or PV-TEG power system:

- A reliable method of re-starting the TEG at temperatures less than -40°F must be designed and verified. The reliable operation of TEGs quoted above is for continuous operation.

- At least two of the RT sites are in locations which might block solar insolation year around. Before any form of PV power system is designed, a reliable record of daily solar insolation must be collected for each site. U1, U2, U3, U4 and U5.

Conclusions with respect to specific salient issues (reliability, safety, cost, etc) addressed by this assessment are summarized in the following paragraphs.

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7.1 RELIABILITY.

Of all evaluated power generation technologies, Radioisotope Thermoelectric Generators (RTGs) are the most reliable. RTGs produce power directly, passively and statically. This means no moving parts to fail, no active thermal control devices to fail, no active electric generator controls to fail, and no fuel supply to fail or run out. All other technologies considered are susceptible to one or more of the aforementioned failure modes.

7.2 SAFETY/ENVIRONMENT.

Of all evaluated power generation technologies, Radioisotope Thermoelectric Generators (RTGs) present the highest safety factors and lowest health risk to the local residents, wildlife, and Air Force maintenance technicians. The two key factors are the reliability of the RTG radiation shielding and container and the inherent risk associated with rotary winged (helicopter) transportation. The RTG containers were manufactured to extremely conservative (safer) standards and have never leaked. The use of any of the other evaluated technologies would require significant high risk air transportation of hazardous materials and significant disruption of the environment associated with the construction of fuel storage facilities.

7.3 COST.

Of all evaluated power generation technologies, Radioisotope Thermoelectric Generators (RTGs) represent the most cost effective. The initial cost have already been paid. There are no fuel costs. Annual radiation safety surveys are accomplished in conjunction with routine electronics maintenance activities and thus constitute minimal cost. If the RTGs are replaced by some other technology, the taxpayers must pay to store the RTGs in *addition* to paying for the annual operation of any alternative.

7.4 CLOSEST COMPETITOR.

At this time, propane-fueled ThermoElectric Generators appear to be the best candidate for immediate replacement of the RTGs. They have proven reliable in Arctic and Antarctic environments at reasonable initial costs. It is possible, however, by the end of the projected useful lifetime of the RTGs other, emerging technologies may prove more economical and safe than the TEGs.

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7.5 OVERALL CONCLUSION.

Of all evaluated power generation technologies, Radioisotope Thermoelectric Generators (RTGs) represent the safest, least disruptive to the environment, most reliable, and most economical approach to supplying electrical power to the Burnt Mountain Seismic Observatory. Table 7.5-1 presents a graphic illustration of the study conclusions. Each block representing a characteristic is shaded according to whether that power system exhibits desirable or undesirable features for the subject characteristic. For example, the Technical Risk associated with RTGs is desirable (lightly shaded block) because of demonstrated performance; whereas, the Technical Risk associated with Fuel Cells is undesirable (darkest shading) because there are significant engineering developments which must be completed. An in-between value of shading is given to average or medium rated characteristics.

TABLE 7.5-1: Graphical Illustration of the Results of the Burnt Mountain Power Assessment.

Power System	Characteristics of Assessment					
	Tech. Risk	Environ. Impact	Safety Risk	Logistics Support	Cost	Reliability
2.1.1 TEG	Desirable	Desirable	Average	Average	Desirable	Average
2.1.2 RTG	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable
2.2 Solar PV	Desirable	Undesirable	Desirable	Desirable	Average	Average
2.3.1 Battery	Undesirable	Desirable	Desirable	Average	Undesirable	Undesirable
2.3.2 Fuel Cell	Undesirable	Desirable	Undesirable	Average	Undesirable	Undesirable
2.4.1 Engine	Desirable	Desirable	Average	Average	Average	Average
2.4.2 Wind	Undesirable	Undesirable	Desirable	Undesirable	Average	Undesirable
2.5 Landline	Desirable	Undesirable	Desirable	Undesirable	Undesirable	Undesirable

☐ Desirable   ▨ Average   ■ Undesirable

The criteria for rating the characteristics of assessment are explained in the following paragraphs. Support for these ratings can be found in the summary sections for each of the power system technologies treated in this report.

Technical Risk...has the candidate power system been reduced to practice? Are there significant engineering developments or modifications needed to adapt existing systems to the Burnt Mountain Seismic Observatory application?

Cost...relative to other candidate power systems, what is the degree of life cycle cost?

Environmental Impact...does normal operation or installation of the candidate power system damage the environment? Does the power system require environmentally disruptive site construction for installation? As it is engineered, how does the operation, installation or maintenance of the candidate power system affect the local environment?

Safety Risk...does handling or servicing the candidate power system pose any safety risk to AF maintenance personnel? Does the power system require the transportation of toxic or flammable materials? Does the operation of the candidate power system represent a risk to fauna, flora or local human population?

Logistics Support...what is the degree of logistics support that the candidate power system requires in terms of helicopter trips per year.

Reliability...has the candidate power system been used in Arctic or Antarctic environments? Does the candidate power system have a proven capability in these harsh environments? Are there reliability indications from other known applications?

8.0 RECOMMENDATIONS

8.1 Continue to operate the RTGs until the end of their useful power life. The first RTG would removed from Burnt Mountain in 2009.

8.1.1 Continue compliance with all radiation safety requirements.

8.1.2 For an added margin of safety conduct annual clearing of combustible materials from the equipment sites.

8.2 Logically and methodically phase out the RTGs as they reach the end of their useful lifetimes.

8.2.1 Conduct site specific surveys to include measurements of temperature, solar insolation, wind conditions and soil analysis.

8.2.2 Continually evaluate the maturing of emerging power technologies to ensure that the optimum technology is selected at the projected time of replacement or sooner.

8.2.3 Field test candidate replacement systems in parallel with RTGs to ensure continuity of operations.

8.3 Plan for the permanent removal and disposal of the RTGs.

8.3.1 Plan for an Environmental Assessment for removing the RTGs from Burnt Mountain.

8.3.2 Secure necessary interagency agreements for the long term storage of the RTGs.

9.0   CONTRIBUTORS TO THE REPORT

Mr. JEFFREY R. BROWN is presently a thermal analyst for aerospace vehicle power systems. Mr. Brown has over ten years of engineering experience with nuclear and thermal systems. His academic credentials include a B.NE. in Nuclear Engineering from Georgia Institute of Technology in 1983, BS in Physics from Georgia College in 1983, MSME. from University of Dayton, Dayton, Ohio in 1987 and is presently a Ph.D. candidate at the University of Dayton, Dayton, Ohio. Mr. Brown has authored 11 technical papers on thermal management issues and nuclear radiation analysis.

Dr. DAVID H. FRITTS, III has over thirty years of experience in several technical disciplines associated with power production technologies. Dr. Fritts received his BSME from Valparraiso University in 1961, MSME from Ohio State University in 1965 and a Ph.D. from Northwestern University in 1970. Over his career, he has published over 35 technical papers and holds 16 US patents. Dr. Fritts has received several awards including the Aero Propulsion and Power Laboratory S.D. Heron Award and he was runner-up for the Federal Professional Employee of the Year.

Mr. EARL GREGORY obtained a B.Sc. degree in Aeronautical Engineering from the Massachusetts Institute of Technology in 1988. He has worked at Wright Laboratory since 1989 in the area of auxiliary power and electromechanical technologies. Mr. Gregory has been involved with several small engine technology programs, and served as the Air Force evaluator on the High Altitude Long Endurance (HALE) engine evaluation. Mr. Gregory currently has a patent pending for a magnetic clutching mechanism for auxiliary power units.

Mr. THOMAS R. LAMP has over twenty-five years of engineering experience in the technical areas of energy conversion, microwave amplifiers, heat pipes, neutral beams and flexible circuits. He received his BS in Engineering from UCLA in 1971. He has published over thirty technical papers on subjects such as microwave helix tubes, heat pipes, thermionic energy conversion, and wide band microwave transmission lines. He also holds three US patents and four invention awards. He serves on a number of committees including chairman of the Nuclear Working Group of the Interagency Advanced Power Group and is a member of the Technical Program Committee for the University of New Mexico's Space Nuclear Power Symposium.

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Mr. TERRY M. TRUMBLE has over thirty years of experience in fire control systems, photovoltaic power systems and computer systems. He received his BSEE and MSEE from the University of Dayton, Dayton, Ohio. Mr. Trumble has received several awards including the Aero Propulsion and Power Laboratory's S.D. Heron Award for technical achievement. Mr. Trumble has over forty technical publications and holds five patents in the areas of fire detection, photochromic dyes and computer technology.

Mr. STEVE VUKSON has over fourteen years experience in the electrochemistry of batteries. He received his BS in Chemical Engineering from Ohio University in 1975 and his MS in Materials Engineering from the University of Dayton in 1993. Mr. Vukson holds two US patents and has published over thirty technical papers in topics ranging from aqueous battery systems to lithium electrochemistry. He is a member of the Department of Energy's Electric Vehicle Readiness Group. Mr. Vukson was appointed as a member of the National Electrical Manufacturers Association and the US Commodity Control Committee for the specification and foreign control of militarily sensitive lithium battery technology.

Mr. JOSEPH A. WEIMER received the BSEE and MSEE degrees from the University of Dayton in 1977 and 1985, respectively. He served four years with the Dayton Power and Light Company as an Electrical Engineer where he was responsible for developing electrical power distribution systems. Mr. Weimer has been with Wright Laboratory since 1981 and he is responsible for the research and development of electrical power and power electronic systems for aircraft. Mr. Weimer has over ten technical publications relating to electrical power and power electronics.

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APPENDIX A

An Environmental Assessment for
The Use of Radioisotope Thermoelectric
Generators

Report No. WAI-104

May 1973
(Revised May 1977)

A-1

To: TECH Ops DIV/LGEB
ATTN: MsgT RIDGLEY

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WAI-104

An Environmental Assessment for
The Use of Radioisotope Thermoelectric
Generators

May 1973
(Revised May 1977)

Submitted to:

Director, Nuclear Power Division, Code 042
Naval Facilities Engineering Command
Department of the Navy
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INTRODUCTION AND SUMMARY

This document represents an assessment of the environmental impact
resulting from Navy operations of radioisotope thermoelectric generators
(RTGs) fueled with byproduct material. This assessment is performed in
compliance with Section 102(2)(c) of the National Environmental Policy
Act of 1969 (NEPA) and according to OPNAVINST 6240.3D, dated 24 April 1975,
with the exception that specific information regarding a particular project
such as project description, existing environment, etc. is necessarily
omitted.

Navy RTGs presently operate under U.S. Nuclear Regulatory Commission
Byproduct Material License No. 45-16359-03 which is the broad license
issued to the Naval Facilities Engineering Command based in part on the
NAVFAC Radiological Safety Guide Series.

The data used in this document were generated by analyses and tests to
assure compliance of the Navy RTGs to the requirements set forth in Title
10 Code of Federal Regulations, Part 71 (NRC), The International Atomic
Energy Agency Safety Series Nos. 6 and 33 (IAEA), and Title 49 CFR,
Parts 173.391 - 173.396 (DOT).

This document considers normal transportation and operation of typical
generators representing terrestrial, ocean bottom and surface/near surface
locations and hypothetical accident conditions associated with transportation
and operation.

It is concluded that there is no adverse environmental impact associated
with the transportation and operation of RTGs covered by the Navy's
License No. 45-16359-03.

I. SYSTEMS DESCRIPTION

The Navy, under the auspices of the Naval Facilities Engineering Command (NAVFAC), uses Radioisotopic Thermoelectric Generators (RTGs) for electrical power generation. An RTG uses the decay heat from a radioisotope, such as strontium 90, to produce electricity from the thermoelectric direct energy conversion process. An RTG generally consists of the encapsulated radioisotopic fuel, the thermoelectric converter, biological shielding (to minimize radiation) and the outer housing. The Navy RTG's fueled with byproduct material have a great deal in common, i.e., the same fuel form, the similar encapsulant around the fuel, and similar thermoelectric converter materials. Individual RTG designs will vary. However, from an environmental standpoint, the fuel (strontium titanate) and its encapsulant is very similar on all RTGs, thus, making an evaluation on each RTG design unnecessary. This will be discussed in the next section. A listing of the RTG inventory for the U. S. Navy is given in Table 1. Some typical RTG designs are shown in Figures 1-3. Figure 2 is a cutaway of a 1 watt URIPS generator to illustrate the above mentioned components. In general, the larger RTGs listed in Table 1 are very similar in construction. There are some differences in the biological shielding design and material, and the outer housing.

The potential applications of RTGs are: (1) terrestrial; (2) bottom-located hydrospace (ocean); and (3) surface/near surface hydrospace (ocean). Power levels of up to 500 W(e) are being anticipated for these applications. At present, the SENTINEL 100F (100W) is the largest RTG in the Navy inventory. The 500W generator would have four (4) capsules identical to the SENTINEL 100F RTG capsules, and thus, the results of this report, regardless of the final configuration of the 500W RTG, would be applicable.

Specific RTG applications are discussed in Section II.B.1 of this document.
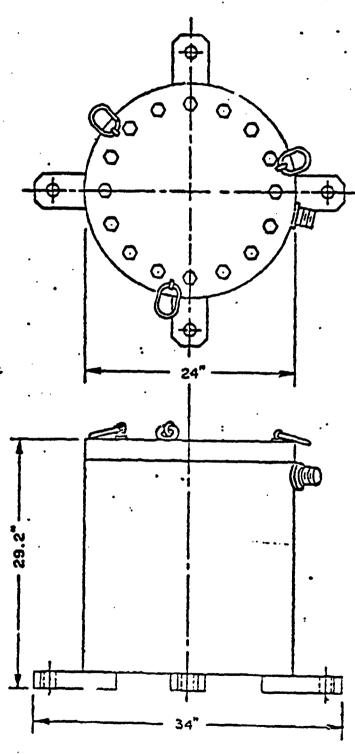
TABLE 1
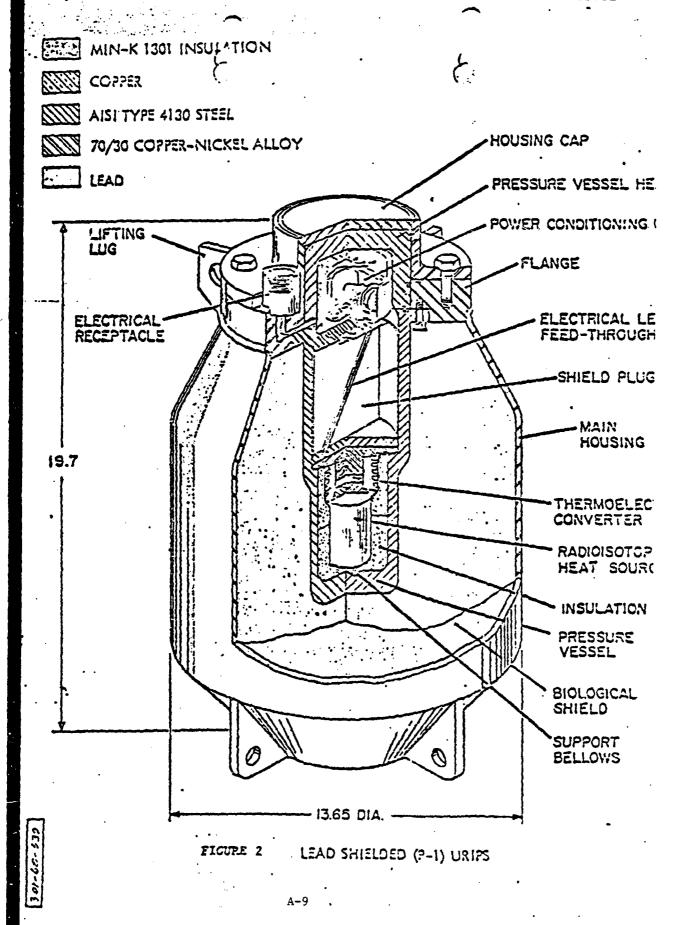
NAVFAC RTG INVENTORY

RTG	DESIGN POWER BOL (WATTS)	DESIGN LIFE (YEARS)	FUEL TYPE	MAXIMUM LICENSED FUEL QUANTITY (CURIES EA)
SENTINEL-25A	25	5	$^{90}SrTiO_3$	125,000
SENTINEL-25C	25	5	$^{90}SrTiO_3$	125,000
SENTINEL-25D	25	5	$^{90}SrTiO_3$	125,000
SENTINEL-25E	25	5	$^{90}SrTiO_3$	125,000
SENTINEL-25F	25	5	$^{90}SrTiO_3$	125,000
SENTINEL-8	7	5	$^{90}SrTiO_3$	40,000
SENTINEL-100F	100	5	$^{90}Sr_2TiO_4$	370,000
SNAP-21	10	5	$^{90}SrTiO_3$	33,000
SNAP-7E	10	10	$^{90}SrTiO_3$	31,000
SNAP-23A	60	10	$^{90}Sr_2TiO_3$	165,000
URIPS-P1	1	5	$^{90}SrTiO_3$	8,200
TRACS-25A	20	5	$^{90}SrTiO_3$	125,000
URIPS-8	8	5	$^{90}SrTiO_3$	56,850
GULF-1-WATT	1	5	$^{90}SrTiO_3$	8,300

FIGURE 1

SENTINEL 8

24"

29.2"

34"

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Legend:
- MIN-K 1301 INSULATION
- COPPER
- AISI TYPE 4130 STEEL
- 70/30 COPPER-NICKEL ALLOY
- LEAD

Labels:
- HOUSING CAP
- PRESSURE VESSEL HE
- POWER CONDITIONING (
- FLANGE
- ELECTRICAL LE FEED-THROUGH
- SHIELD PLUG
- MAIN HOUSING
- THERMOELEC CONVERTER
- RADIOISOTOP HEAT SOUR(
- INSULATION
- PRESSURE VESSEL
- BIOLOGICAL SHIELD
- SUPPORT BELLOWS
- LIFTING LUG
- ELECTRICAL RECEPTACLE

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FIGURE 2   LEAD SHIELDED (P-1) URIPS

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FIGURE 3

SENTINEL-25D

25.6"

27.0"

29.9"
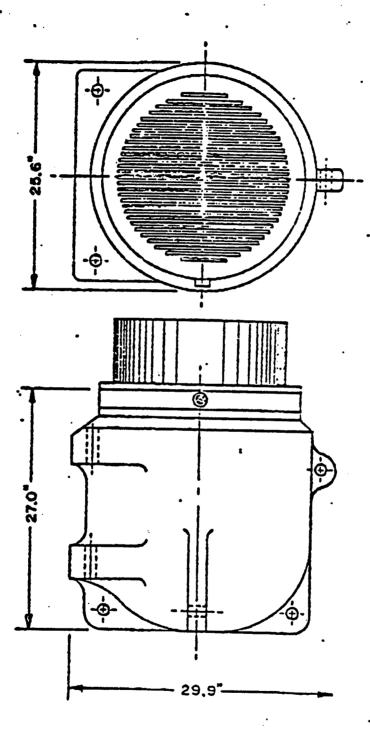
II. THE PROBABLE ENVIRONMENTAL IMPACT OF THE PROPOSED ACTION

A. Transportation

1. Normal Transportation

An RTG is normally transported by special van or waterway carrier. Under certain circumstances rail or air transport is required. On water, the RTG would be transported by barge or ship. Transportation is covered by Title 49, Code of Federal Regulations. All RTGs are designed to comply with these regulations. If the RTG in its container (if a container is necessary) does emit radiation in excess of 200 millirem per hour at any point on its exterior and emits more than 10 millirem per hour at 3 feet from any accessible external surface, the container must be shipped in a transport vehicle (except aircraft) assigned for the sole use of that consignee, and un-loaded by the consignee from the transport vehicle in which originally loaded. The following radiation levels must not be exceeded by a sole use, closet shipping vehicle.

a. 1,000 millirem per hour at 3 feet from the external surface of the packge.

b. 200 millirem per hour at any point on the external surface of the car or vehicle.

c. 10 millirem per hour at 6 feet from the external vehicle surface.

d. 2 millirem per hour in any normally occupied position in the car or vehicle.

RTGs are self-shielding. Radiation levels for the RTGs as packaged for shipment do not exceed the 200 mr/hr surface and 10 mr/hr three feet criteria. No effect on the evnironment is anticipated with the normal transportation mode.

2. Hypothetical Accident Tests

The radioisotope thermoelectric generators must be designed to withstand normal conditions of transport and certain hypothetical conditions as prescribed by the Codes of Federal Regulations, 10 CFR 71 and 49 CFR 171. The performance criteria which the RTG designer must use to assess the RTG against empirically establishe accident damage test conditions include impact percussion, thermal thermal shock, mechanical shock, pressure, leakage, etc, In speci cases, the International Atomic Energy Agency (IAEA) Safety Series Nos. 6 and 33 must be complied with. Safety Series No. 33 is a guide to the safe design, construction and use of RTGs for certain

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land and sea applications. It specifies the following fuel
capsule test criteria which is applicable whenever the RTG
is to be used or travel over foreign soil.

IAEA Capsule Test Criteria (Safety Series No. 33)

Impact Test

The capsule shall fall onto the target from a height of
9 meters. The target shall be a flat, horizontal surface
of such a character that any increase in its resistance
to displacement or deformation upon impact by the capsule
would not significantly increase the damage to the capsule.
A target of this type may be provided by a steel plate at
the upper surface of a block of concrete of mass at least
10 times that of any housing that is to be dropped onto
it. The block should be set on firm soil and the steel
plate on its upper surface should be at least 1.25 cm.
thick and wet-floated onto the concrete so as to be in
intimate contact with the latter.

Percussion Test

The capsule shall be placed on a sheet of lead which is
supported by a smooth solid surface and struck by the flat
face of a steel billet so as to produce an impact equivalent
to that resulting from the free fall of 7 kilograms through
1 meter. The flat face of the billet shall be 2.5 centimeters
in diameter with the edges rounded off to a radium of not less
than 3 millimeters. The lead, of hardness number 3.5 to 4.5
on the Brinell scale and not more than 25 millimeters thick,
shall cover an area greater than that coverd by the capsule.
A fresh surface of lead shall be used in each test.

Thermal Test

The capsule shall be heated to a temperature of $800^\circ C$ and
it shall be held at that temperature for a period of 30 minutes
before being allowed to cool.

Thermal Shock Test

The capsule shall be heated to its maximum operating temp-
erature and then plunged in water at zero degrees centigrade
temperature where it shall be left for 10 minutes.

Pressure Test

The capsule shall be shown to be able to resist an external
pressure of 1000 bars, (i.e., 10^8 Newtons per square meter.

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Leakage Test

After each of the above tests, the capsule shall be shown to have retained its original leak-tightness within the accuracy of the chosen method. Any commonly accepted leakage test may be used, provided it is of a sensitivity comparable with the detection of leakage of 10^{-4} (STP) cm^3/sec. If this degree of leakage can be detected, the test requirements will not have been met.

The SENTINEL 100F capsule was tested by the U. S. Naval Ordnance Laboratory to comply with the IAEA, Series 33 capsule tests. For all tests, the capsule passed. Additionally, a bare SNAP-21 capsule withstood an 1850°F (1010°C) fire for two hours.[1] It should be noted that all RTG capsules are similar in construction (the capsule material is Hastelloy "C", a nickel base alloy which combines corrosion resistance with excellent high temperature properties), and are all right circular cylinders. Although the only capsules tested were the SENTINEL-100F and the Gulf 1 watt capsule (and SNAP-21 for similar environments) the test results are, in general, applicabel to all other RTGs because: (1) The effect of the RTG housing and shield which offers substantial proection was not consiuered; and (2) the current RTG capsules are similar in construction as seen in Table II.

TABLE II

RTG Capsule Material and Capsule Dimensions

RTG	CAPSULE MATERIAL	CAPSULE DIMENSIONS
URIPS-P1	Hastelloy C	2.1"D x 2.1"L
SNAP-21	Hastelloy C	3.2"D x 3.3"L
SENTINEL 100F	Hastelloy C	5.6:D x 12"L
SENTINEL 25 (A, C, D, F)	Hastelloy C	3.75"D x 10.3"L
SENTINEL 8	Hastelloy C	3.75"D x 4.9"L

Other Tests

Depending upon the RTG application, corrosion, vibration, irradiation and creep tests may also be specified.

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[1] SNAP-21 Program, Phase II, "Operational Safety Analysis", Report MMM 3691-0048, May 1969, prepared jointly by the U.S. Naval Radiological Defense Laboratory and the 3M Company.

Housing Tests

All RTGs must also be designed such that the housing shall survive mechanical, thermal, external pressure and, in certain cases, corrosion, vibration, irradiation and creep environments. The tests covered in the IAEA Safety Series No. 33, pp. 20-22 need not be carried out if it can be shown, by methods of calculation or model techniques, that the requirements of the test could be met. The mechanical test includes two drops on a target in order to obtain maximum damage. The thermal test requires that the housing be exposed to a thermal radiation environment of 800°C for 30 minutes with air emmisivity coefficient of 0.9, assuming the surfaces of the capsule have an absorption coefficient of 0.8. The pressure test requires that the housing maintain integrity at the operating depth, plus a "safety margin to allow for operational or accidental contingencies".

An extensive evaluation of transportation accidents was performed for the SNAP-21 RTG.[1] Such accidents, as a head-on collision with another truck, total burial in earth, chemical attack and truck-train collision were evaluated. The maximum credible fire environment, for a gasoline truck collision was analyzed (similar to the IAEA thermal environment). It was concluded that the impact energy from a head-on collision could rupture the RTG housing and biological shield but, that the heat source (capsule) would survive. In light of the 10 CFR 71 and 49 CFR 171 licenses for the Sentinel and URIPS RTG [2] it can be reasonably assumed that <u>all</u> RTG capsules will survive the transportation accident environments intact and in <u>most</u> cases the housing would not be broken or damaged. No radioactive material would be released.

The case of an RTG falling or dropping into the deep ocean will be discussed in the next section.

B. RTG Operation

1. Normal Operation

The U.S. Navy applications, as previously mentioned, can be grouped as: (1) terrestrial; (2) bottom-located hydrospace (ocean); and (3) surface/near surface hydrospace (ocean). The SENTINEL 8 will be selected to illustrate a terrestrial application (although SENTINELS are used for all categories), the URIPS 8 to represent a bottom-located

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(2)"Safety Analysis Underwater Radioisotope Power Source (URIPS)", May, 1968, Aerojet-General Corporation.

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application and the SENTINEL 25D to represent a surface/near surface application. These RTGs are shown in Figures 1-3, respectively. It should be pointed out that there is considerable interchangeability in RTGs for terrestrial and undersea applications. The three RTGs selected are representative for each type of application.

One of the key conclusions reached is that no RTG in the Navy inventory will cause any appreciable environmental effect for any of the above applications. This will be discussed further in the next section.

a. Terrestrial Application

The primary consideration for a normal operation is the ionizing radiation field. Since all applications would be in restricted areas, no effect on the general population would occur. The dose rates at the boundaries of the RTG installation must not exceed the levels specified in the Federal Regulations (10 CFR, Part 20) which establish permissible levels of radiation in unrestricted areas. These permissible levels are:

(1) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of 2 mr in any one hour.

(2) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of 100 mr in any seven consecutive days.

(3) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of 0.5 rem in a year.

Although the measured dose rates from a generator are low, precautions are required to assure that the conditions of the regulations are met. These precautions are covered in the NAVFAC Radiological Safety Guide Series and typically a radiation control area of about five feet in radius around an RTG is sufficient to ensure compliance with the regulations.

No adverse environmental effect is anticipated for RTGs operated in terrestrial applications.

One terrestrial application at present is a SENTINEL 8 located on San Miguel Island off the coast of California in a weather station. The facility consists of a skeletal aluminum structure, sensors and weather-proof boxes which house transmitters, receivers and data-handling electronics.

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The station is powered by a 28-volt battery of nickel-cadmium cells which are trickle-charged by the RTG.

The RTG installation site is an area approximately 22' X 22'. The RTG is placed on steel matting approximately 8' X 8'. The perimeter of the site is marked by steel posts connected by several strands of barbed wire. The fence is five feet high and is marked on each side as "Radioactive Materials Area" and Radiation Area". In addition, the installation is marked with a sign indicating the nature of the installation and a telephone number to call for inquiry or emergency.

b. **Bottom-Located Application**

The URIPS (as well as the SNAP-21 and certain SENTINEL RTGs) is designed for normal operation to depths of approximately 23,000 feet. Three URIPS-P1 RTGs have been implanted in the Pacific Ocean since 1970 to power deep ocean transponders. The URIPS can be safety implanted in ocean waters and/or embedded in silt indefinitely without danger of radioactive material release since the capsule is designed to withstand pressures greater than 23,000 feet (10,000 psi) and the capsule material (Hastelloy C) will not corrode through before 300 years [3] See Section II.B.1.c.(1) and II.B.1.c.(2) also.

For normal operation, there is negligible corrosion of the URIPS steel pressure vessel and the 70% copper - 30% nickel anti-fouling liner has a corrosion rate of only-15 mils/year in sea water.

The housing of the SNAP-21 and SENTINEL generators is also corrosion resistant for more than their designed mission lifetimes.

No adverse environmental effect is anticipated for RTGs operated in bottom-located applications.

Corrosion of generator hardware in sea water, however, can contribute various metal ions to the environment. Metal ions of interest from an environmental standpoint are primarily lead, uranium, tungsten and copper and their alloys. Both copper and lead exhibit excellent resistance to marine environments and copper and lead alloys are used extensively in maritime applications. Their resistance to marine environments are the result of their inherent insolubility in sea water in addition to their ability to form films of corrosion

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[3] "Safety Analysis, Underwater Radioisotope Power Source (URIPS)". Aerojet General, Report AN-1619, May 1968.

products that are resistant to erosion by turbulently flowing sea water[4]. Kennametal, Inc. [5] which supplies the tungsten shielding material for RTGs reports that the corrosion rate of their materia, after a 2,016 hour synthetic sea water test is:

$$2.1 \text{ mg/dm}^2/\text{day} \quad \text{Equivalent to 0.16 mil for W-2 tungsten}$$

Uranium alloyed with 8% molybdenum, which is generally used for RTG shielding, is the most corrosion resistant uranium alloy. Its corrosion rate in 40-60°F water is:

$$< 10^{-7} \text{ mg/cm}^2/\text{hr} \quad [6]$$

Since the rate of corrosion of copper, lead, tungsten and uranium are slow in comparison to the mixing and dilution rate expected in a marine environment, toxic concentrations of these metal ions will not be produced to impose any negative impact on the aqueous environment.

c. Surface/Near Surface Application

Typical missions for a SENTINEL 25D RTG are sonar detection for submarine or surface vessels or weather stations. The SENTINEL power system may be implanted at some depth in combination with a pinger which, when accurately located, may be detected by a ship and used as a navigation aid. The RTG housing is designed to withstand sea water corrosion for the mission lifetime. For a normal mission, the RTG would be recovered with no environmental effect. Recovery of the RTG is anticipated and worthwhile.

In the event that the RTG is left permanently in the ocean, the housing would eventually corrode through. The time to corrode through is difficult to determine at this point, due to the rather wide range of corrosion rate data. The anchoring mechanism would most likely completely corrode and the generator would either float ashore or drift out to sea. If the generator floated ashore, it would be recovered intact without any adverse effect on the environment. In the event that the generator drifted out to sea, it might eventually fall to the ocean floor at an undefined bottoming point and present a situation similar to (b) above for bottom-located applications. Again, the RTG would present no hazard to the environment.

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(4) Metals Handbook - American Society for Metals, Metals Park, Ohio, 8th Editic

(5) Letter communication from A.L. Echtenkamp of Kennametal, Inc., dtd March 1973

(6) "Aqueous Corrosion of Uranium and Its Alloys" - TID7587, AEC-Euratom Conference, Brussels, Belgium, October 14-17, 1959, James T. Waber.

A specific potential application for the SENTINEL 25D was the Naval Oceanographic and Meterological Automatic Device (NOMAD) buoys, cancelled in early 1972. The purpose of these systems was to function as remote, deep water moored, automatic, unattended weather stations. Each NOMAD buoy was to be equipped with one SENTINEL 25D and electrical storage and conditioning equipment to power the meterological station.

(1) Seawater Corrosion of Fuel Capsules

The value conservatively recommended for sea water corrosion of Hastelloy C is 0.1 mil/year [7]. Hastelloy C does not suffer pitting or general corrosion in sea water, stagnant or moving. The value of 0.1 mil/year for corrosion is thus used in all calculations to obtain lifetime of the capsule in sea water.

(2) Solubility of Strontium Titanate Fuel

Leach rates were determined [8] on five $^{90}SrTiO_3$ fuels having densities ranging from 62 to 92% of theoretical. The low density samples were recovered from SNAP-7A fuel capsules after seven years of operation. The high density samples were prepared by hot pressing. The samples were intact after an immersion of 76 days in distilled water. The data were fitted to a single equation by a method of least squares and are presented in Figure 4 with the 95% confidence limits. A single equation to represent the data is as follows:

$$\ln R = -0.5235 \; \ln T - 2.5987$$

where,

$$R = \text{leach rate, mg cm}^{-2} \text{ day}^{-1}$$

$$T = \text{time, days}$$

(7)
   Strontium 90 Power Project, Final Summary Report, MND-SR-1676, March 1960.

(8)
   "Strontium 90 Data Sheets", ORNL-4358, March 1969, Oak Ridge National Laboratory.
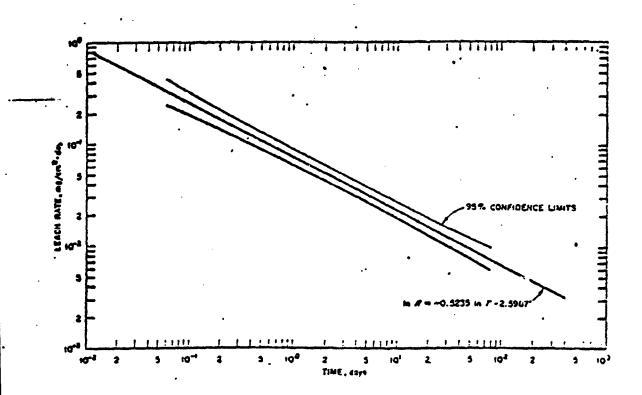
FIGURE 4

Leach Rate of ^{90}SrTiO$_3$ as a Function of Time

Using the leach rate for $SrTiO_3$, the amount of fuel that could be dissolved, and the approximate radioactivity was determined as shown below.

$$M = A \int_0^T R \, dt$$

where,

M = Total mass dissolved (mg)

A = Surface area (341 cm^2)

R = Solution Rate $mg\text{-}cm^{-2}\text{-}Day^{-1}$

T = Time in days

therefore,

$$M = 341 \int_0^T (e^{-0.5235 \ln T - 2.5987}) \, dt$$

The solution is obtained by the substitution: $x = \ln T$;

$$M = 53.24 \, e^{0.4765 \ln T}$$

For one year (365 days), the result is 0.886 gm. Solution times of 10, 20 and 100 years were also calculated and are presented in Table II, assuming release at 300 years. It was assumed that the fuel pellet surface area was 341 cm^2, which corresponds roughly to a 10 W(e) capsule (SNAP-21). This area would be slightly larger for some SENTINEL capsules, although not enough to affect the conclusiont.

Radioactivity is determined using the standard decay formula:

$$A = A_o e^{-\lambda t}$$

where,

A = Activity at time (t)

A_o = Initial activity

λ = Decay constant = $0.693/T_{1/2}$

where,

$T_{1/2}$ = half-life (years) = 27.7 years for 90-Sr

t = Time (years)

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TABLE II

DISSOLUTION OF $^{90}SrTiO_3$ IN WATER

(Assuming Release after 300 years)

Time (After Release) (years)	Fuel Remaining in Capsule (gm)	Activity Remaining in Capsule (curies) *	Fuel Dissolved (gm)	Activity Dissolved (curies)
0	938	17.6	0	0
1	937.11	17.29	0.89	0.011
10	935.35	13.57	2.65	0.033
20	934.31	10.65	3.69	0.046 (Maximum)
100	930.06	1.43	7.94	0:0099

* Based on 32,000 curies at time of fueling (SNAP-21)

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It can be seen that only extremely small amounts of
radioactivity could be released to the ocean. Additionally,
the fuel would be dispersed over many years of dissolution
to give very low levels of concentration.

As seen in Table I, the SENTINEL 100F RTG will utilize
the strontium orthotitanate (Sr_2TiO_4) fuel form. Some
solubility data as taken from Oak Ridge [8] is presented
below in Table III.

"A static solubility study of titanate fuels using a
particle size of ≤ 177 microns with 9 g of fuel per
200 ml of dissolver solution gave the following results."

TABLE III

Water Solubility of Sr_2TiO_4 at Room
Temperature and at 66°

| | Micrograms of fuel per ml of dissolver solution | | | |
Days	Deionized Water	Natural Seawater	Synthetic Seawater	0.1 N HCl
	Sr_2TiO_4 at Room Temperature			
7	9,856	8,683	9,386	11,050
28	7,337	9,357	9,599	9,988
48	9,298	9,832	9,980	10,427
78	7,456	9,478	9,243	9,826
98	8,209	9,799	9,860	10,290
161	10,103	10,454	10,766	9,816
	Sr_2TiO_4 at 66°			
7	12,857	11,417	14,528	13,860
28	10,044	10,888	13,461	13,063
48	12,916	11,643	14,376	13,480
78	11,846	11,307	13,912	12,716
98	13,995	12,313	14,670	13,585
161	10,135	13,607	16,635	15,302

If it is conservatively assumed that all particles are
177μm in diameter, the surface area would be 705 cm^2
for 9 gm of fuel. If, as is actually the case some are
smaller than 177μm, the surface area would be larger
and yield a lower leach rate. Thus, 705 cm^2 will be
conservatively used to calculate the Sr$_2$TiO$_4$ leach rate.

For seven days, in natural seawater at room temperature, the
leach rate can be calculated as follows:

$$R, mg \ cm^{-2} \ day^{-1} = \frac{8.683}{(705)(7)} = 1.76 \times 10^{-3} \ (8,683 \ micrograms)$$

For SrTiO$_3$, the equivalent leach rate at 7 days is approximately
10^{-1}. Thus, based on the raw data available for Sr$_2$TiO$_4$, it is
considerably less soluble that SrTiO$_3$ (1-2 orders of magnitude)
and would not result in any appreciable radioactivity being
dissolved in water.

2. **Operational Accidents**

   a. **Terrestrial Applications**

     Several situations can be postulated in which the RTG can
     be impaired. In all cases the fuel capsule will remain
     intact for hundreds of years, by which time, the total
     fuel activity will have decayed to less than one curie.
     In addition, the RTG housing, thermal insulation, and
     shielding would have to be eroded away to even expose the
     bare fuel capsule. This makes an exposure by the "elements"
     extremely unlikely.

     (1) **Vandalism**

       The possibility of theft is considered unlikely since
       an RTG is not a saleable item (except perhaps to a
       foreign power) nor does the RTG have direct value to
       an individual. Size, weight and radioactive danger
       signs reduce the possibility of theft. While an
       irrational person might gain access to the unit and
       attempt to disassemble it, it is doubtful that the
       fuel capsule could be exposed.

     (2) **Crushing**

       As mentioned in the section for Transportation Accidents,
       the capsule and, in most cases, the RTG would survive the
       rather severe mechanical environments. No situation can
       be postulated where crushing such as from rock slides
       constitutes a hazard in terms of causing a fuel release.

     (3) **Loss of Shielding**

       A situation could occur in which the RTG biological shield
       could be cracked or broken by mechanical forces. The

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radiation level would increase significantly over
the accepted levels for direct, long term human
exposure. However, the possibility of uninformed
people coming into contact with the RTG is extremely
remote since the sites are controlled and generally
remote, such as small unpopulated island, rocks, etc.,
and would not expose humans.

b. **Bottom-located Application**

As discussed in Section II.B.1.c.(1), the seawater corrosion
rate for Hastelloy C is approximately 0.1 mil/year. Capsule
lifetimes would be approximately 300 years conservatively, up
to 23,000 feet. Thus, in the event that the RTG is permanent
left on the bottom, the ^{90}Sr activity would be reduced to a
fraction of a curie (Section II.B.1.c(2)).

A study was performed[9] to determine the thermal effects
from heat sources buried in wet sand. A relationship was
determined between the source surface/ground surface temp-
erature differential, the depth of burial and the radius
of the cylindrical source. It was found that, for RTG cap-
sules, buried as deep as five feet under the ocean bottom,
the steady state temperature differences between the system's
surface and the environment was calculated to be less than
$100°F$. It can be concluded that silt burial presents no
safety problem.

c. **Surface/Near Surface Application**

At the present time, no thermal, structural or other environ-
ment more severe than the transportation environments discuss
in Section II.A.2, can be identified. This would include
fires on a buoy, impact with a submerged or surface object
(e.g., ship, submarine or drops from some height on a buoy or
other surface structure).

Due to standard handling practices, the likelihood of an RTG
falling greater than 30 feet onto a hard surface is remote.
Thus, no environment that could release fuel on the surface
can be identified. The most probable accident would be re-
leasing the RTG in water and allowing it to fall to the
bottom. This has already been discussed in the previous
sections. No release of the fuel by pressure and/or cor-
rosive action would occur before approximately 300 years.

---

(9)

"Heat Transfer from Radioisotopic Heat Sources Buried in the Ocean Floor",
USNDRL-TRC-86, November, 1966, U.S. Naval Radiological Defense Laboratory
Schrock, V.E. and Kesawan, K

III. ANY PROBABLE ADVERSE ENVIRONMENTAL EFFECTS WHICH CANNOT BE AVOIDED
      SHOULD THE PROPOSAL BE IMPLEMENTED

For terrestrial and surface/near surface applications, the RTG would
most likely be recovered at the end of its mission life (5-10 years
at present) and present no threat to the environment. As previously
discussed, the environmental effects during normal transportation are
inconsequential.

For deep ocean applications, there is a chance that the RTG would be
left on the ocean floor if economic recovery is not feasible. It was
concluded in Section II that the fuel capsule would remain intact for
approximately 300 years by which time the fuel would have decayed to
a fraction of its original activity and slowly be dissolved and dis-
persed in the deep ocean. Under these conditions, adverse environmenta:
effects would be negligible.

For example, the dissolution of one curie of fuel into the ambient sea-
water could result in a localized (890 meter radius) concentration of
~0.34 p Ci/liter which is small compared to the natural occurring radic
nuclides in the ocean of ~340 p Ci/liter. [10] This example is conserva-
tive since it assumes immediate dissolution of the fuel, whereas, as
previously shown in Section II.B.1(c)(2), the fuel would be dispersed o
many years of dissolution, with accompanying decrease of activity to gi
very low levels of concentration. The centration of 0.34 p Ci/liter you
be equivalent to the existing ocean surface concentration of ^{90}Sr. [10]
The quantity of one curie would be quite small in comparison to the [10]
existing total quantity of ^{90}Sr (32 million curies) in the oceans.

---

[10] "Radioactivity in the Marine Environment", National Academy of
     Sciences, 1971.

IV. ALTERNATIVES TO PROPOSED ACTION

At present, there are power supplies that can be used for remote
terrestrial, oceanographic (surface/near surface) and deep ocean
applications. These power supplies are fuel cells, batteries and
power cables. Each of these has been used in the past and will
be discussed below.

Batteries - Batteries are characterized by having high
power densities (watts/lb) but, are limited
in their operating life (usually up to one
year).

Fuel Cells- Fuel cells also have high power densities but
must be refueled periodically and cannot operate
continuously, unattended, for up to five years.

Cables   - Power cables can be attached to the assigned
project from a conventional coastal power source.
However, it can become impractical to place cables
beyond a certain length, (i.e., a few miles from
shore). This is both due to economics and the
potential line losses.

Characteristics of the above power supplies are shown in Figure 5
where the coordinates are power level in watts and operating time
in hours. The curves correspond to the various types of power
sources. It can be seen that for a typical power requirement of
25 watts, only RTGs and cables are practical for periods greater
that 4,500 hours. As just discussed, there are many cases where
power cables are unacceptable.

Thus, for unattended long life and long term reliability applica-
tions, there is no satisfactory alternative to RTGs as a power
supply.

FIGURE 5 Alternative Power Supplies

V. THE REALTIONSHIP BETWEEN LOCAL SHORT-TERM USE OF ENVIRONMENTS AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

Radioisotope Thermoelectric Generators (RTGs) are build to meet the Code of Federal Regulations Title 10 and Title 49 to ensure that when handled under normal and accident conditions, the exposure of individuals and the population at large would be below accepted dose limits. In special cases, the International Atomic Energy Agency (IAEA) Safety Series Nos. 6 and 33 are complied with depending upon the RTG application. Because RTGs are designed to preclude the release of radioactive materials, they should not present any detriment to long term productivity. The above-stated compliance with standards certifies safety for man, plant or animal should any come within the proximity of the RTG site.

The short term use of environments by RTG installations is inconsequential, spacewise, and will neither add to nor detract from the maintenance and enhancement of long term productivity. RTGs occupy only two to five cubic feet of volume and are usually installed in controlled and/or remote areas. The radioisotope thermoelectric generators provide long life, reliable, unattended power sources for important Navy requirements in the navigational, military and weapon support areas.

VI. ANY IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES WHICH WOULD BE INVOLVED IN THE PROPOSED ACTION SHOULD IT BE IMPLEMENTED

Except for the hypothetical accident case where an RTG would remain on the ocean floor, the power supplies and their ancillary equipment are retrievable and hence, pose no loss to out domestic resources.

In the event that an RTG system is irretrievable, the dollar value and quantity of the lost materials are generally insignificant from a resource standpoint since a generator only weighs between 2000-6000 pounds and does not contain any strategic materials. Typically an RTG consists of the following materials:

Radioisotope Fuel	-	Strontium Titanate
Fuel Cladding	-	Hastelloy "C" (nickel alloy)
Biological Shield	-	Tungsten, depleted uranium, lead
Insulation	-	Min K (diatomaceous earth material)
Thermoelectric Modules	-	Lead-tin-tellurium, Bismuth
Heat Rejection Head	-	Aluminum alloy, Iron, Beryllium
Generator Housing	-	Aluminum, Copper alloy, Iron, Titanium

The highest percentage of generator weight is in the biological shield and the loss of that amount of either lead, tungsten or depleted uranium would not constitute a serious depletion of our resources, since the annual U.S. supply of lead is more than one million tons, tungsten exceed 25 million pounds, and uranium, more than 10,000 tons [11].

The radioisotope, SR-90, constitutes a special case from a resource standpoint. Strontium 90 is produced from power reactor fission produce wastes and its supply is increasing. Hanford [12] will have the capability of producing about 30 megacuries of encapsulated Sr-90 per year starting in fiscal 1974. The maximum radioisotope loss due to an irretrievable generator would not exceed 370,000 curies of Sr-90 which is the amount in a SENTINEL 100F.

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[11] "Mineral Facts and Problems", U.S. Bureau of Mines Bulletin 650, U.S. Department of Interior 1970

[12] Communications from Mr. Lowell Miller, Division of Applied Technology USAEC.

APPENDIX B

Operation Manual for Sentinel
Radioisotope Thermoelectric Generators
Used in AFTAC Seismic Sensor
Stations, Burnt Mountain, Alaska

Report No. TES-3198

February 1985
Revised June 1985

OPERATION MANUAL FOR SENTINEL
RADIOISOTOPE THERMOELECTRIC GENERATORS
USED IN AFTAC SEISMIC SENSOR
STATIONS, BURNT MOUNTAIN, ALASKA

REPORT NO. TES-3198

FEBRUARY 1985

REVISED JUNE 1985

This manual was prepared for the
Department of the Air Force
under Contract F09603-84-C-1117

TELEDYNE
ENERGY SYSTEMS

110 West Timonium Road
Timonium, Maryland 21093

FOREWARD

This manual provides important information on the Sentinel 25A, 25E, 25F and 100F radioisotope thermoelectric generators. RTG users and health physics personnel should be thoroughly familiar with its contents. Compliance with the instructions contained herein will insure satisfactory performance of the RTGs and prolong their useful life.

TABLE OF CONTENTS

I. INTRODUCTION

The equipment purchased by the U.S. Air Force under Contract No. F09603-84-C-1117 includes a Sentinel 25F radioisotope thermoelectric generator (RTG), 20 watt power conditioner units (PCUs), 50 watt PCUs, RTG-PCU interconnecting cables, shipping pallets, and a handling sling. This equipment will be used in conjunction with Sentinel 25A, 25E, and 100F RTGs already owned by the Air Force to power seismic sensors and related items located near Burnt Mountain, Alaska.

The following chapters describe the Sentinel 25A, 25E, 25F, and 100F RTGs and provide instructions for their installation and use. Instructions are also included for handling and transporting the generators and isolating the cause of unsatisfactory performance within the RTG/PCU power system. Pertinent radiological safety information is also provided, including recommended radiation protection standards and practices and procedures for conducting RTG surveys and leak tests.

This manual also describes the RTG-PCU interconnecting cables, RTG shorting plugs, RTG load box, shipping pallets, and handling sling and provides instructions for their use.

Information regarding the installation, use, and check-out of the 20 and 50 watt PCUs can be found in TES Report Nos. 3197 and 3200, respectively.

II.   EQUIPMENT DESCRIPTION

A.   SENTINEL 25A (S/N 004)

The Sentinel 25A generator, shown in Figure II-1, is comprised of the following components: the fuel capsule assembly or heat source; an inner radiation shield; thermal insulation; a thermoelectric module; a pressure housing and lid; and a finned radiator assembly. It is designed to operate within the following range of environmental conditions:

1.	Ambient air temperature	-40°F to + 120°F*
2.	Ambient air pressure	20 to 32 inch Hg
3.	Seawater temperature	+ 28°F to ÷ 90°F
4.	Seawater pressure	Up to 500 psi
5.	Humidity	100% relative humidity in salt water atmosphere

* Will operate at rated power up to approximately 80°F.

The heat source for the Sentinel 25A is strontium-90, fabricated as $SrTiO_3$ and encased in a Hastelloy C capsule. The tungsten inner shield and cast iron housing reduce radiation levels to less than 10 mR/hr at one meter from the generator's surface. Approximately 5% of the heat resulting from the decay of the radionuclide is converted in the thermoelectric module to electricity which is available for useful electrical power. The remainder of the heat is rejected as waste. Thermal insulation is used in the space between the inner shield and housing to channel the heat through the module.

The generator is a right circular cylinder with a cast iron housing. Its principle dimensions are shown in Figure II-2. The housing has four lugs spaced at 90-degree intervals on its bottom. Each lug has a hole that serves as a lifting and/or tie-down point. There is an additional lifting lug on the side of the generator. The

1	Housing
2	Insulation
3	Inner shield
4	Fuel capsule
5	$SrTiO_3$ fuel
6	Thermoelectric module
7	Lid
8	Auxillary radiator

FIGURE II-1.   SENTINEL -25A
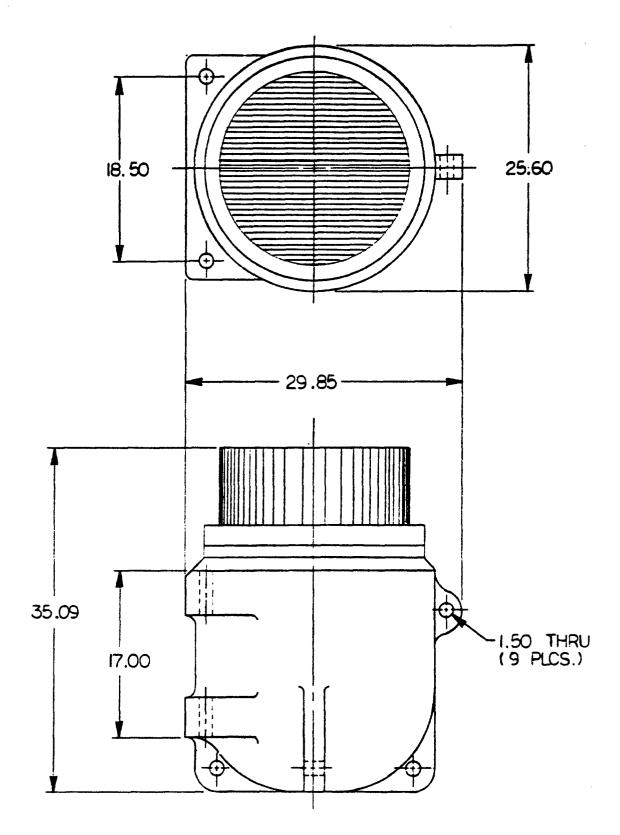
FIGURE II-2.   SENTINEL 25A EXTERNAL DIMENSIONS (IN INCHES)

generator will operate in either of the positions shown in Figures II-1 and II-2.

Waste heat is partially dissipated through cooling fins which are an integral part of the generator's cover. The balance of the heat is rejected through the sides and bottom end.

The generator's electrical power outlet is a sealed 4-pin connector located on the side of the housing. See Figure II-3. One positive and one negative pin are provided. The connector is keyed by non-symmetrical pin spacing so that the shorting plug and RTG-PCU interconnecting cable cannot be mated incorrectly.
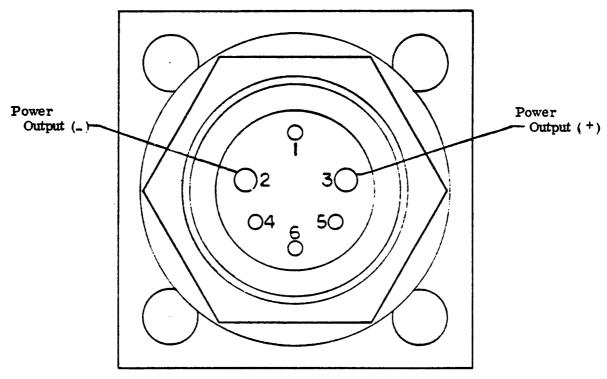
A shipping pallet is provided with the generator to facilitate handling and to provide a means of securing the generator during transport. The generator is attached to the pallet by four bolts. See Figure II-4. The generator weighs 3000 pounds and its shipping pallet weighs 285 pounds.
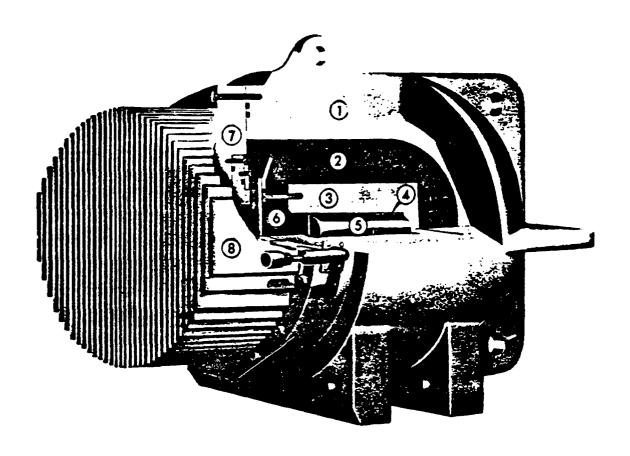
B. SENTINEL 25E (S/N's 008-010 and 017-020)

The Sentinel 25E generator, shown in Figure II-5, consists of the following components: the fuel capsule assembly or heat source; an inner radiation shield; thermal insulation; a thermoelectric module; a pressure container consisting of a housing and lid; and a finned radiator assembly. It is designed to operate within the following range of environmental conditions:

1.	Ambient air temperature	-40°F to +120°F*
2.	Ambient air pressure	0.9 to 4 atmospheres
3.	Seawater temperature	28°F to 88°F
4.	Seawater pressure	Up to 10,000 psi
5.	Humidity	0 to 100 percent in saltwater atmosphere

* Will operate at rated power up to approximately 80°F.

(Pins 1, 4, 5, and 6 are dummies)

FIGURE II-3.   SENTINEL 25A ELECTRICAL CONNECTOR
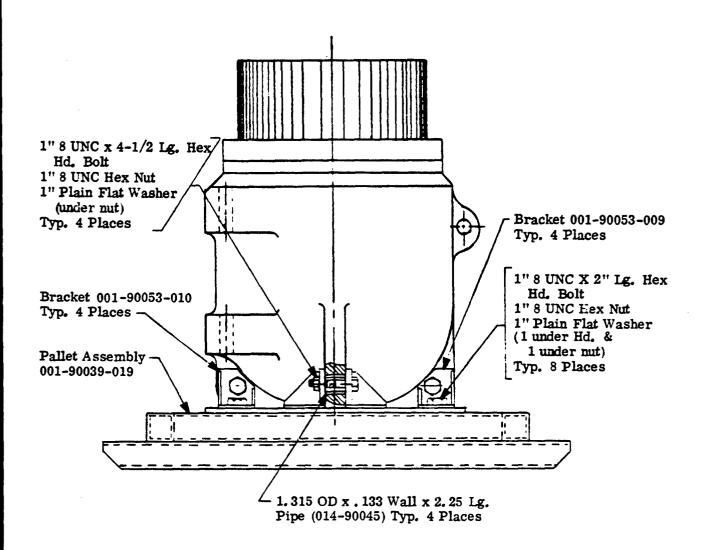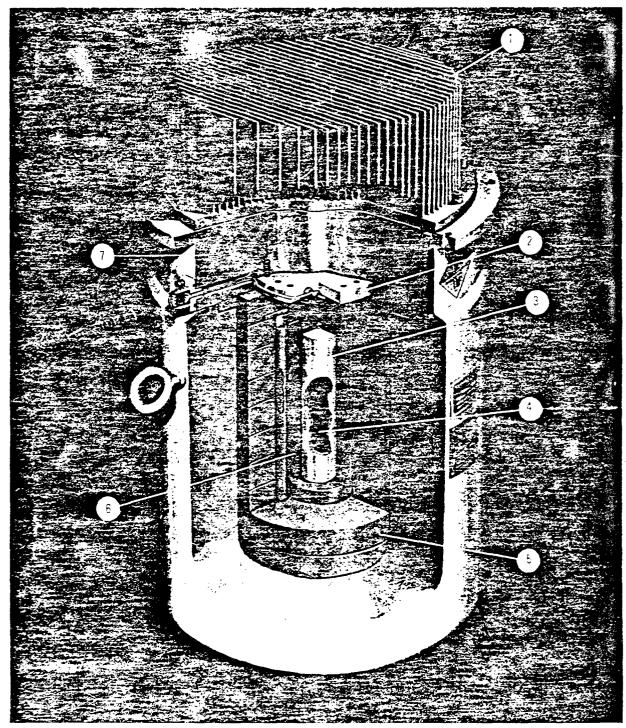
1" 8 UNC x 4-1/2 Lg. Hex
   Hd. Bolt
1" 8 UNC Hex Nut
1" Plain Flat Washer
   (under nut)
Typ. 4 Places

Bracket 001-90053-009
Typ. 4 Places

Bracket 001-90053-010
Typ. 4 Places

1" 8 UNC X 2" Lg. Hex
   Hd. Bolt
1" 8 UNC Hex Nut
1" Plain Flat Washer
(1 under Hd. &
   1 under nut)
Typ. 8 Places

Pallet Assembly
001-90039-019

1. 315 OD x . 133 Wall x 2. 25 Lg.
Pipe (014-90045) Typ. 4 Places

FIGURE II-4.   SENTINEL 25A GENERATOR/SHIPPING
                PALLET MOUNTING HARDWARE

FIGURE II-5. SENTINEL 25F GENERATOR

The heat source for the RTG is strontium 90 fabricated as strontium titanate and encased in nickel base superalloy capsule. (A fuel capsule using simulated fuel has successfully completed hydrostatic pressure tests to 17,500 psi.)

A tungsten shield block, into which the fuel capsule is inserted, provides the bulk of the unit's radiation shielding. This inner shield, coupled with the shielding provided by the generator housing, reduces radiation levels to less than 10 mR/hr at one meter from the generator's surface.

Approximately 5 percent of the heat produced by the decay of the radionuclide is converted to electricity by the thermoelectric module. Thermal insulation is used in the space between the inner shield and the housing to channel the heat through the module. The module is self-contained and sealed with its own inert atmosphere.

The housing and the lid form the complete pressure containment for all of the components previously mentioned. The housing is in the form of a right circular cylinder and is machined from forged carbon steel. Its principle dimensions are shown on Figure II-6. Threaded holes are provided in the housing for the purpose of attaching the generator to its shipping pallet via mounting brackets. See Figure II-7. The lid is also machined from forged carbon steel and is fastened to the housing by 16 alloy steel socket head bolts. The lid is machined with a flange, 27 inches in diameter and one inch thick, that can be utilized as a mounting interface. The lid to housing interface is sealed with two Viton 'O' rings. (The pressure housing assembly has been successfully tested at external pressures up to 15,000 psi with no detectable leakage.)

Since only 5 percent of the decay heat is converted into electrical power, the remainder of the heat must be rejected. To accomplish this, the Sentinel 25E is provided with a finned radiator assembly. This assembly is fabricated from an aluminum alloy and is bolted to the lid with 8 aluminum alloy bolts.

The electric power and instrumentation outlet for Sentinel 25 E Serial Nos. 017, 018, 019, and 020 is a sealed 8-pin connector located on the side of

Pallet Mounting Bracket

8 Holes - .875/.882 Dia.
Equally Spaced on a
25.000 Dia. B.C.

29.6 Typ

27.0 Dia.

8.75

1.00

31.6

25.6 Dia.

3.00
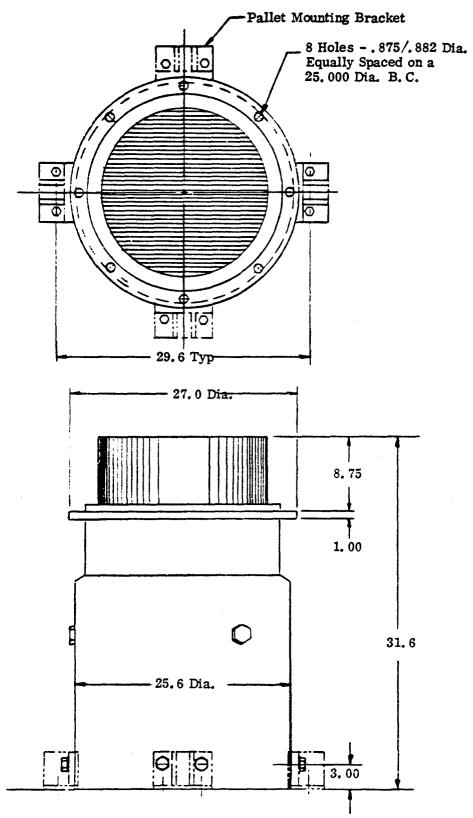
FIGURE II-6.   SENTINEL 25E EXTERNAL DIMENSIONS (IN INCHES)

B-14
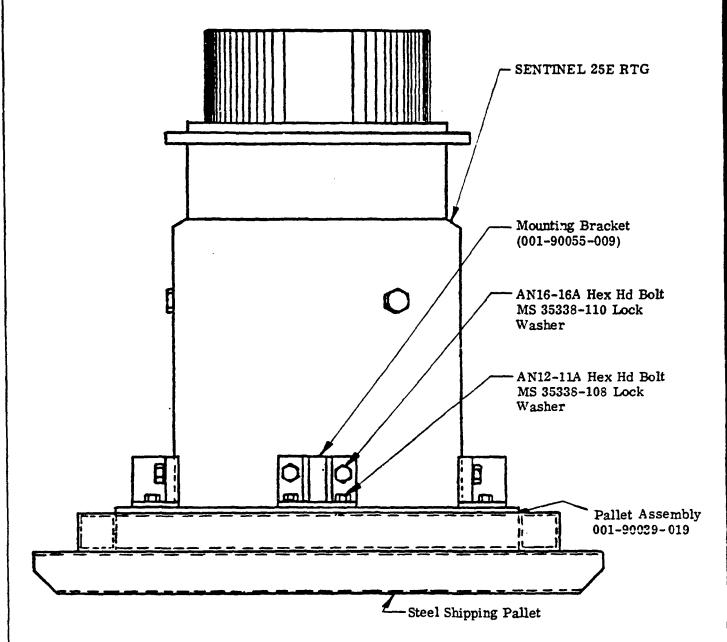
FIGURE II-7.   SENTINEL 25E GENERATOR/SHIPPING PALLET
MOUNTING HARDWARE

the lid. See Figure II-8. Four of the connector pins are used for power connections (two positive leads and two negative leads) and the remaining four pins are used for two chromel-alumel thermocouples. Both thermocouples are located on the hot plate of the thermoelectric module. Receptacles on S/N's 008, 009, and 010 DO NOT have pins for thermocouple outputs. See Figure II-8a. All receptacles are keyed by non-symmetrical pin spacing so that the shorting plugs and RTG-PCU interconnecting cables cannot be mated incorrectly.

The Sentinel 25E weighs 4165 pounds and its shipping pallet weighs 285 pounds.

C. SENTINEL 25F (S/N 014)

The Sentinel 25F generator, shown in Figure II-9, is comprised of the following components: the fuel capsule assembly or heat source; a radiation shield; thermal insulation; a thermoelectric module; a pressure housing; a lid; and a finned radiator assembly. It is designed to operate within the following range of environmental conditions:

1.	Ambient air temperature	-40°F to + 120°F*
2.	Ambient air pressure	0.9 to 4 atmospheres
3.	Seawater temperature	28°F to 88°F
4.	Seawater pressure	Up to 500 psi
5.	Humidity	0 to 100 percent in saltwater atmosphere

* Will operate at rated power up to approximately 80°F.

The fuel or heat source for the RTG is strontium 90, fabricated as strontium titanate, and encased in a stainless steel liner and then in a nickel base superalloy fuel capsule.

A tungsten shield block, into which the fuel capsule is inserted, provides the unit's radiation shielding. This shield, coupled with the inherent spacing provided inside the generator housing, reduces radiation levels to less than 10 mR/hr at one meter from the generator's surface.

B-16

FIGURE II-8. SENTINEL 25E ELECTRICAL CONNECTOR
(S/N's 017, 018, 019, 020 ONLY)

Power Output (+)

Power Output (-)

Power Output (-)

Power Output (÷)
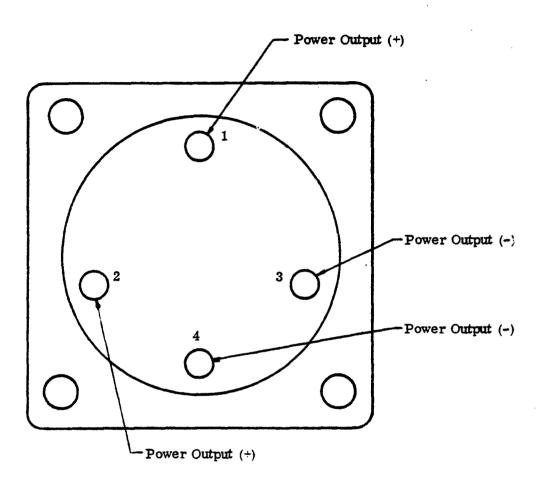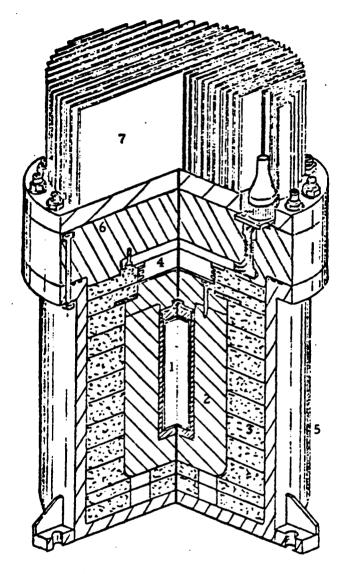
FIGURE II-8a.   SENTINEL 25E ELECTRICAL CONNECTOR
(S/N's 008, 009, 010 ONLY)

1. Heat Source
2. Biological Shield
3. Thermal Insulation
4. Thermoelectric Module
5. Pressure Housing
6. Lid
7. Finned Radiator Assembly

FIGURE II-9.   SENTINEL 25F GENERATOR

Approximately 5 percent of the heat produced by the decay of the radionuclide is converted to electricity by the thermoelectric module. Thermal insulation is used in the space between the shield and the housing to channel the heat through the module. The module is self-contained and sealed with its own inert atmosphere.

The housing and the lid form the complete pressure containment for all of the components previously mentioned. The housing is in the form of a right circular cylinder. Its principle dimensions are shown on Figure II-10. The housing is machined from a welded assembly of 6061-T6 aluminum. Four welded brackets are provided on the housing base for the purpose of attaching the generator to its shipping pallet. See Figure II-11. The lid is also machined from 6061-T6 aluminum and is fastened to the housing by 14 aluminum alloy bolts. The lid to housing interface is sealed with two Viton 'O' rings. A similar housing assembly has been successfully tested at external pressures up to 750 psi with no detectable leakage or deformation.

Since only 5 percent of the decay heat is converted into electrical power, the remainder of the heat must be rejected. To accomplish this, the Sentinel 25F is provided with a finned radiator assembly. This assembly is also fabricated from an aluminum alloy and is bolted to the lid and vessel flange with 16 aluminum alloy bolts.

The generator's electric power and instrumentation outlet is a sealed 8-pin connector located on the top surface of the lid. See Figure II-12. Four of the connector pins are used for power connections (two positive leads and two negative leads) and the remaining four pins are used for two chromel-alumel thermocouples. Both thermocouples are located on the hot plate of the thermoelectric module. The connector is keyed by non-symmetrical pin spacing so that the shorting plugs and RTG-PCU interconnecting cable cannot be mated incorrectly.

The Sentinel 25F weighs 1360 pounds and its shipping pallet weighs 285 pounds.

FIGURE II-10.   SENTINEL 25F EXTERNAL DIMENSIONS (IN INCHES)

AN 12-45
AN 960-1216 UN HD
(3/4-16 UNF Hardware)

Generator
Mounting Bracket

Pallet Assembly
001-90039-049

Spacer

AN 315-12R
MS 35338-108
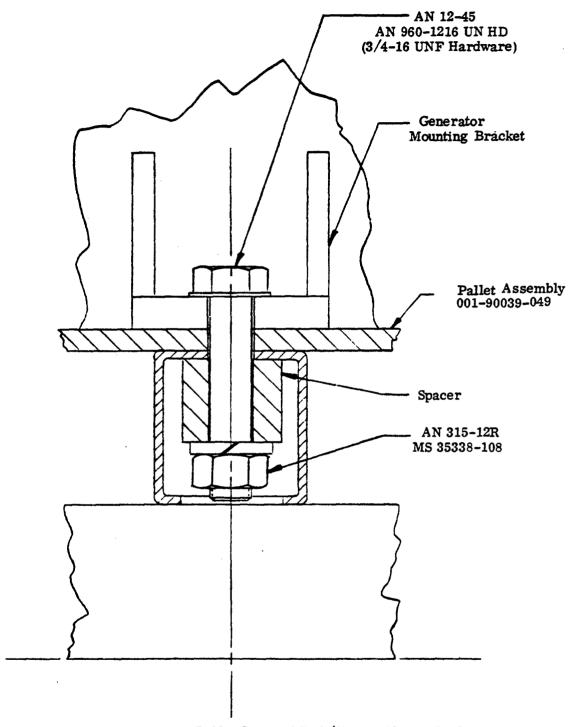
FIGURE II-11.   SENTINEL 25F GENERATOR/SHIPPING PALLET
MOUNTING HARDWARE

Power Output (-)

T/C #2 (+)

T/C #1 (-)

T/C #1 (+)

T/C #2 (-)

1

2

3

4

6

5

7

8

Power Output (+)

Power Output (-)

Outboard

Power Output (+)
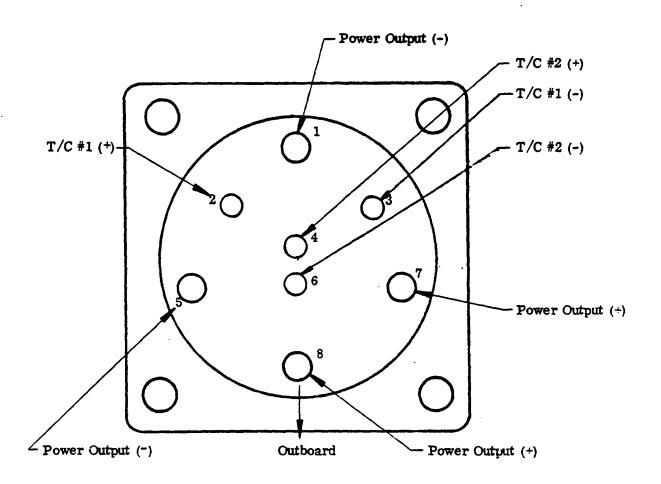
FIGURE II-12.   SENTINEL 25F ELECTRICAL CONNECTOR

D.   SENTINEL 100F (S/N 001)

The Sentinel 100F generator shown in Figure II-13, is comprised of the following components: a fuel capsule assembly or heat source; a radiation shield; thermal insulation; a thermoelectric module, a housing and lid, and a finned radiator. It is designed to operate within the following range of environmental conditions:

1.	Ambient air temperature	-10°F to + 120°F*
2.	Ambient air pressure	0.9 to 4 atmospheres
3.	Seawater temperature	28°F to 88°F
4.	Seawater pressure	Up to 500 psi
5.	Humidity	0 to 100 percent in saltwater atmosphere
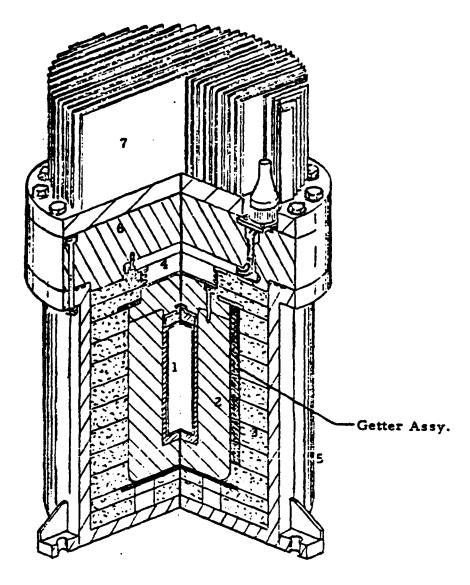
* Will operate at rated power up to approximately 80°F.

The fuel capsule assembly is the RTG's heat source. The assembly consists of pelletized strontium 90 in the titanate form, encased in a nickel base superalloy capsule.

The RTG's radiation shield is a tungsten assembly which houses the fuel capsule. The assembly consists of a shield body and end plug and is fabricated from pressed and sintered tungsten. The shield, coupled with the inherent spacing inside the generator housing, reduces radiation levels to less than 10 mR/hr at one meter from the generator's surface.
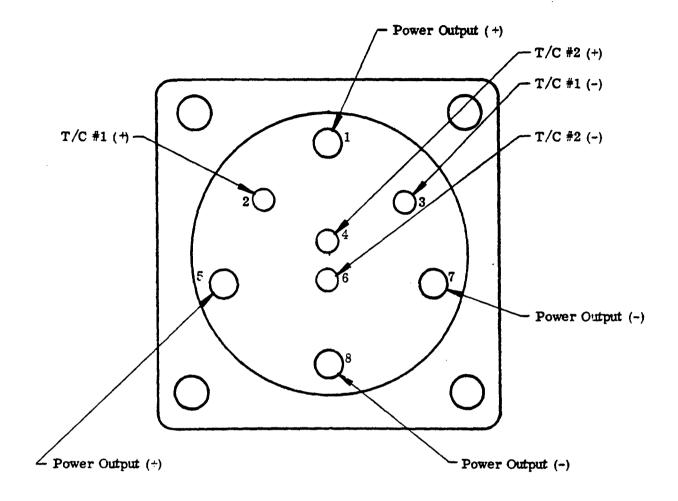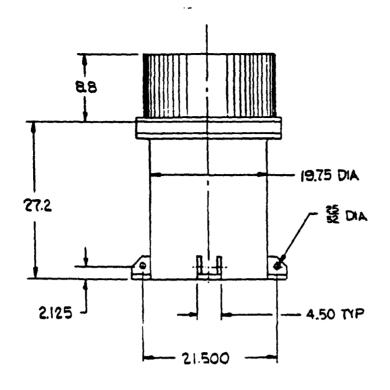
Approximately six percent of the heat produced by the decay of the radionuclide is converted to electricity by the thermoelectric module. The module is self-contained and sealed with its own inert atmosphere.

Thermal insulation is used in the space between the shield and the housing to direct most of the heat through the thermoelectric module. The thermal insulation material is Min-K, a Johns Manville Corporation product. The insulation is "baked out" prior to installation to drive off water vapor and organic binder materials. Getter materials are utilized in the RTG to capture long-term outgassing products.

— Getter Assy.

1. Heat Source
2. Biological Shield
3. Thermal Insulation
4. Thermoelectric Module
5. Pressure Housing
6. Lid
7. Finned Radiator

FIGURE II-13.   SENTINEL 100F GENERATOR

The housing and lid form the complete pressure vessel containing all of the components previously discussed. The housing is in the form of a right circular cylinder. Its principle dimensions are shown on Figure II-14. The housing is machined from a welded assembly of 6061-T6 aluminum. Four welded brackets are provided on the housing base for the purpose of attaching the RTG to its shipping pallet. See Figure II-15. The lid is also machined from 6061-T6 aluminum and is fastened to the housing by 18 aluminum alloy bolts. The lid to housing interface is sealed with two Viton O-rings.

Since only about six percent of the decay heat is converted into electrical power, the remainder of the heat must be rejected. The heat rejection is accomplished by means of a finned radiator bolted to the RTG lid. The radiator is comprised of a number of fins made from 1/8 inch thick aluminum sheet welded to a 6061-T6 aluminum alloy plate. The assembly is bolted through the lid with 16 aluminum alloy bolts and nuts.

The generator's electric power and instrumentation outlet is a sealed eight-pin connector located on the top surface of the lid. See Figure II-16. Four of the connector pins are used for power connections (two positive leads and two negative leads) and the remaining four pins are used for two chromel alumel thermocouples. Both thermocouples are located on the hot plate of the thermoelectric module. The connector is keyed by non-symmetrical pin spacing so that the shorting plug and RTG-PCU interconnecting cable cannot be mated incorrectly.

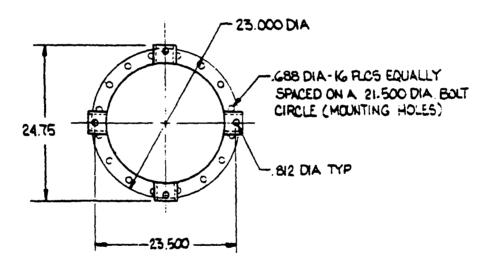The Sentinel 100F weighs 2728 pounds and its shipping pallet weighs 385 pounds.

E. RTG-PCU INTERCONNECTING CABLES

All RTG-PCU interconnecting cables are 18 feet long with a molded neoprene-covered connector on one end and an MS-type connector on the other end. The MS connector attaches to the PCU. Not every cable can be used with each RTG. Each

5/8 Dia. Bolt
16 Pics., Equally spaced on
25.625 Dia. B.C. with
2 holes omitted

30.38 Typ

27.50 Dia.

27.275 Typ

Hole for
1" Dia. Bolt (Typ)

45.67

34.92

1.06
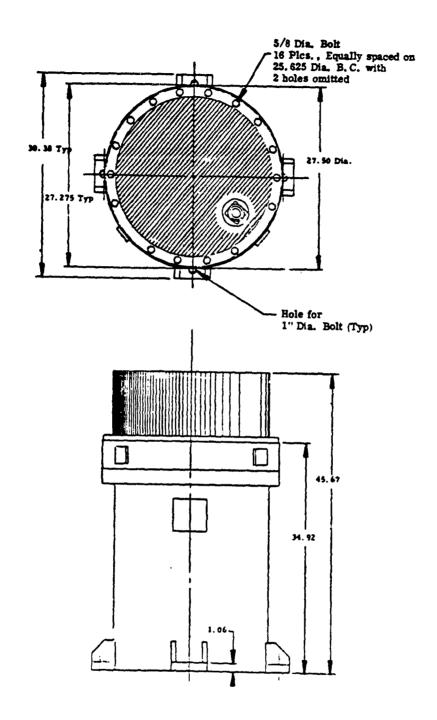
FIGURE II-14.   SENTINEL 100F EXTERNAL DIMENSIONS (IN INCHES)

Finned Head

SENTINEL 100F RTG

AN17-23A Bolt
4 Places
(Pallet is tapped)

Pallet Assembly
001-90039-069
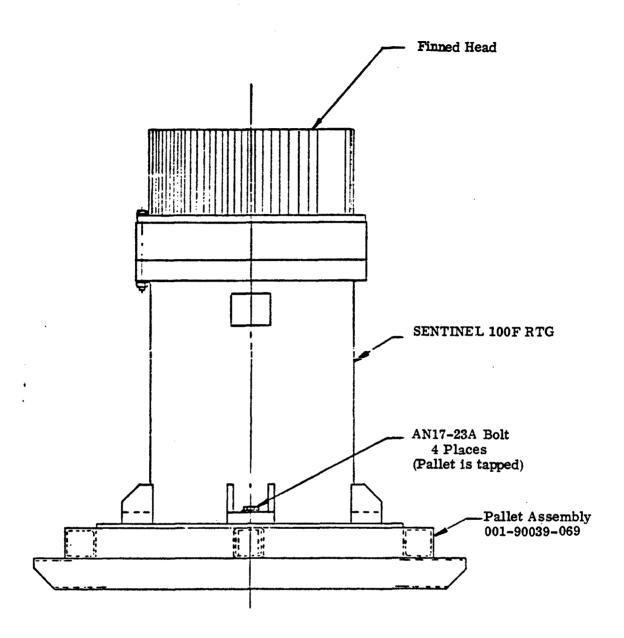
FIGURE II-15.   SENTINEL 100F GENERATOR/SHIPPING
PALLET MOUNTING HARDWARE
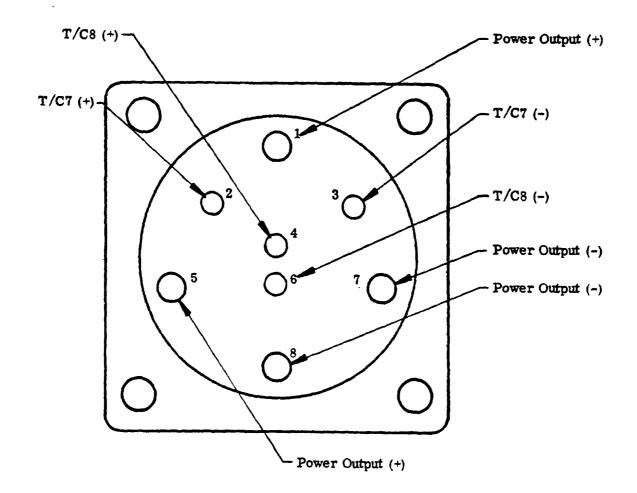
FIGURE II-16.   SENTINEL 100F ELECTRICAL CONNECTOR

cable and the RTG(s) it may be used with are shown in the following table:

Cable (TES Part Number)	RTG Model/Serial Number(s)
014-50006-039	25A/004
014-50006-019	25E/008-010
014-50006-009	25E/017-020
014-50006-029	25F/014
014-50006-009	100F/001

Furthermore, every cable is marked (on both ends) with its TES Part Number and the Serial Number(s) of the RTG(s) it may be used with. Each connector is constructed so that it cannot be mated incorrectly.

F. SHORTING PLUGS

RTGs must be placed on "short-circuit" whenever they are shipped, during periods of storage, and whenever they are disconnected from their PCUs for more than 2 hours. Each RTG has been provided with a molded, neoprene-covered shorting plug. The plug mates with the RTG's electrical connector and provides connections between the positive and negative power pins to short-circuit the generator's output. Shorting plugs should be mated with RTGs as follows:
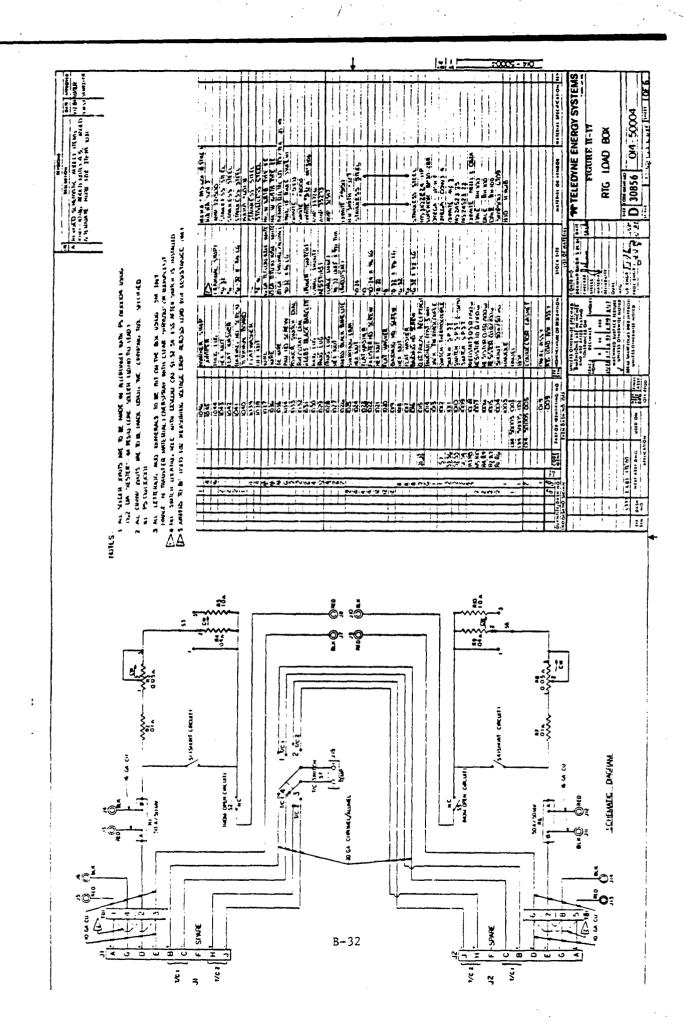
Shorting Plug	RTG Model/Serial Number(s)
Not Available	25A
014-50007-001 (TES)	25E/008-010
5601-3208-H000 (Burton)	25E/017-020
5601-3208-H000 (Burton)	25F/014
5601-3208-H000 (Burton)	100F/001
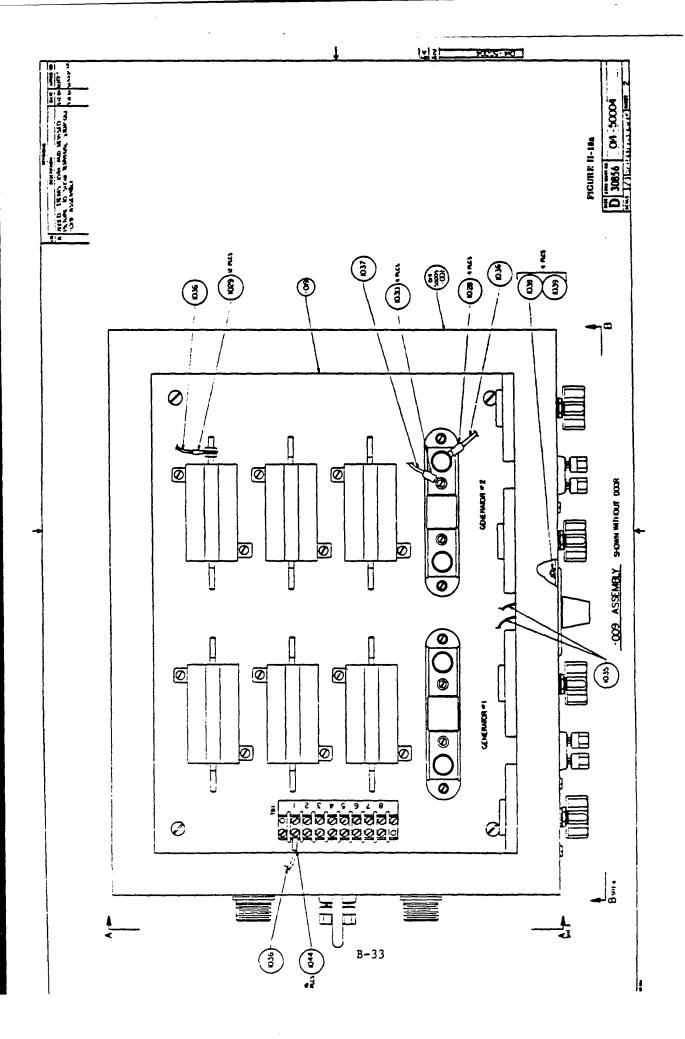
G. RTG LOAD BOX
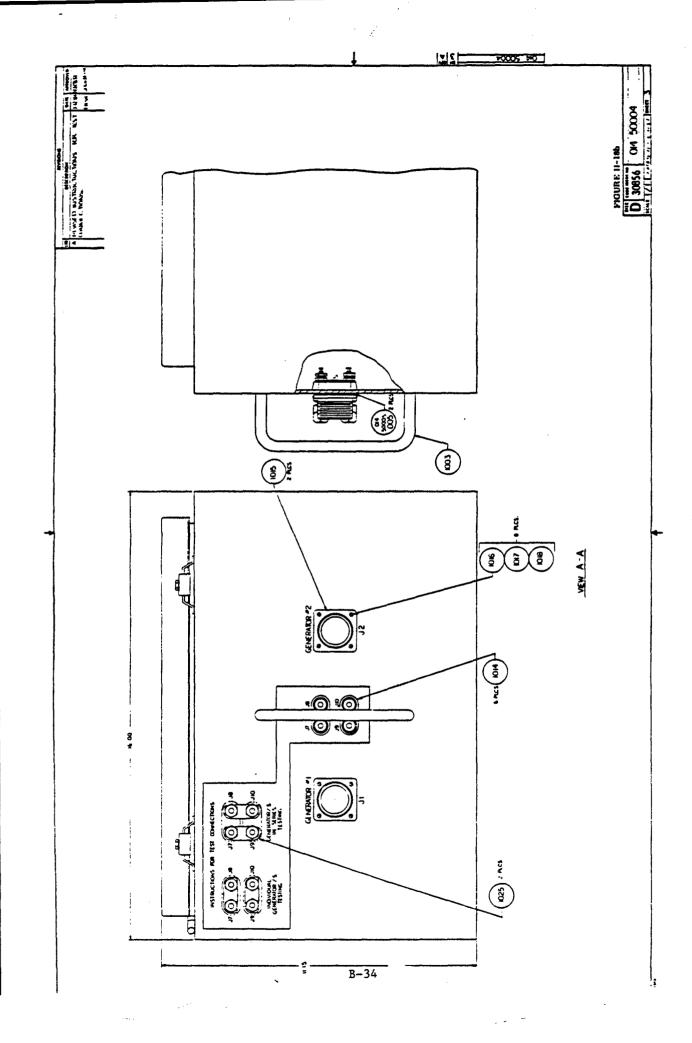
Situations may arise where it would be necessary to measure an RTG's output characteristics. For example, in the process of isolating a system (RTG-RTG-PCU) power output problem, it may be necessary to determine an RTG's output voltage and current at a particular load (or loads). In this case and others, some convenient means must be available for applying various loads across an RTG's output. TES has supplied a load box for this purpose. Figure II-17 is the electrical schematic of the box, and the physical arrangement of its components is shown on Figure II-18. The box can be used to load two RTGs independently and measure each RTG's output voltage and current. It can also be used to load two RTGs connected in series and measure the output voltage and current of the pair. A means is also provided for measuring open circuit voltages. Operating instructions are discussed in Chapter VI in conjunction with RTG check-out and troubleshooting.
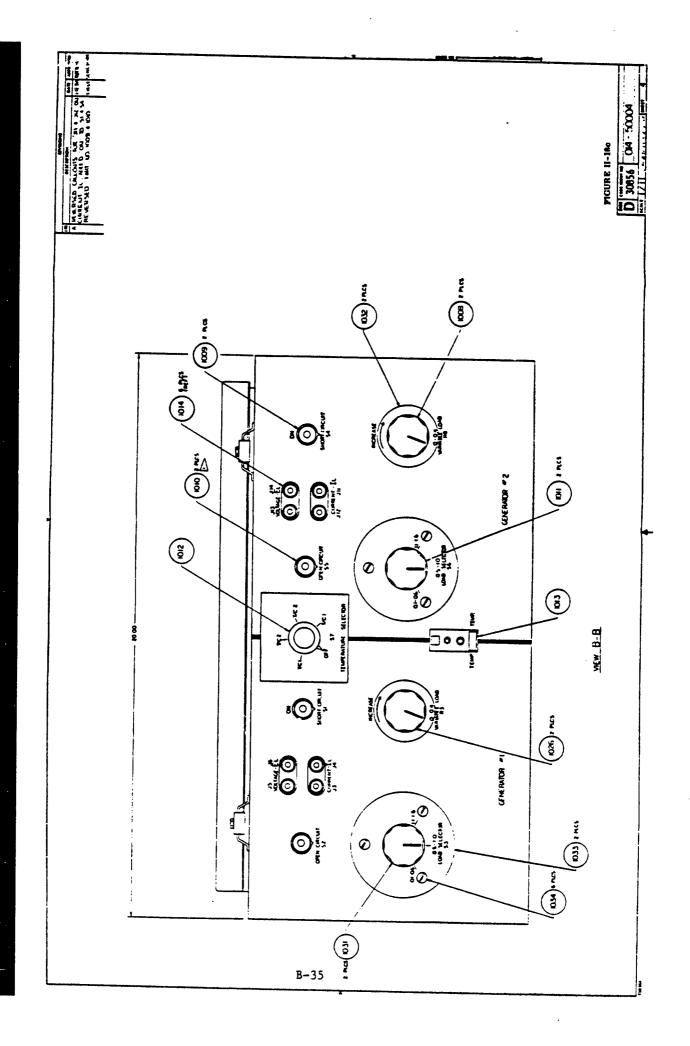
H. HANDLING SLING

The handling sling assembly consists of a spreader bar and two wire-rope "legs." The spreader bar has a ring bolt (for attaching the lifting device) and two eye bolts (for attaching the legs). The legs are connected to the spreader bar and RTG with shackles provided with the assembly. Figure II-19 shows how the spreader bar and legs are configured. The sling can be used with generator models 25E, 25F, and 100F. NOTE: Eye bolts must be installed in the RTG's upper flange before the legs can be attached. See Chapter IV, Section H for instructions.

NOTES:

SCHEMATIC DIAGRAM

FIGURE II-17

TELEDYNE ENERGY SYSTEMS

RTG LOAD BOX

D | 30856 | 014-50004

FIGURE II-18a

-009 ASSEMBLY SHOWN WITHOUT DOOR

B-33

FIGURE: 11-18b

VIEW A-A

GENERATOR #1

GENERATOR #2

J1

J2

INSTRUCTIONS FOR TEST CONNECTIONS

GENERATOR/S IN SERIES TESTING

INDIVIDUAL GENERATOR/S TESTING

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FIGURE II-18

VIEW B-B

TES Part Number
014-90000-009

5/8" Anchor Shackle
Safe Working Load 6,500 Lbs

TES Part Number
014-90001-009

5/8" Anchor Shackle
Safe Working Load 6,500 Lbs

Test Loads:

24,500 Lbs

12,250 Lbs   12,250 Lbs

FIGURE II-19.   SENTINEL 25E, 25F, AND 100F HANDLING SLING

III. GENERATOR PERFORMANCE

A detailed discussion of RTG performance is given in TES Report No. 3189, "Determination of RTG Pairings, AFTAC Seismic Sensor Stations, Burnt Mountain, AK." (Nov. 84). This report contains the I/V characteristic of each RTG as of August, 1984 and provides data which can be used to plot a predicted I/V characteristic for each RTG at "end-of-mission" (October 1995). It also provides each RTG's open-circuit voltage and internal resistance as a function of equilibrium current. This information can be used in conjunction with the test procedures provided later in this manual to determine if an RTG is operation properly.

IV. GENERATOR TRANSPORTATION AND HANDLING

A. CERTIFICATES OF COMPLIANCE

All Sentinel RTGs have been certified to meet the Nuclear Regulatory Commission packaging standards set forth in 10 CFR Part 71. NRC Certificate of Compliance No. 4888 covers the Sentinel 25A, 25E, and 25F RTGs. The Sentinel 100F is covered by Certificate of Compliance No. 5862. Note that these certificates do not authorize shipment. Authorization is provided by 10 CFR 71.12 once a licensee registers as a "user" of the certificates and has an NRC-approved quality assurance plan covering transportation "activities" (shipping papers, markings, labelling, package preparation, etc.).

B. SHIPPING CONFIGURATION

The Sentinel 25 series of RTGs and the Sentinel 100F are certified for shipment without any special shipping container. However, they must be attached to the steel pallets (or equivalent) provided with the generators. A cage is sometimes used to protect an RTG's surface finish, but it is not a manadory requirement. RTGs must not be covered and they should be kept at least one foot from bulkheads, other cargo, and any other obstructions which might restrict the flow of air around the generators.

C. SHIPPING MODES

Sentinel RTGs are certified for shipment in vessels, cargo-only aircraft, motor vehicles, and rail cars.

NOTE: Sentinel RTGs contain what is defined as a "highway route controlled quantity" of radioactive material (49 CFR 173. 403(1)). Because of this, there are special requirements a motor vehicle carrier must meet. Not all carriers meet these requirements and your shipping department should be made aware of this. Also, there

is certain information the carrier must provide the shipper and a report the shipper must make to DOT. See 49 CFR 177.825 and 49 CFR 173.22 (C) for details.

D. SHIPPERS RESPONSIBILITIES

In general, the shipper is responsible for insuring that RTGs are offered to a carrier in accordance with Title 49, Code of Federal Regulations (DOT). This means that the RTGs must be packaged, marked, and labelled as required by 49 CFR. It also means that shipping papers must be completed as specified in 49 CFR. The "packaging" matter has been taken care of by TES, as evidenced by the Certificates of Compliance identified in Paragraph IV.A. Marking, labelling, and shipping paper requirements are summarized in Paragraphs IV. E and IV. F below. Other requirements imposed by DOT, such as maximum contamination levels are currently not a problem for RTGs but the regulations should be checked to insure these requirements have not been changed or new ones added. See 49 CFR 173.

E. SHIPPING AND RECEIVING PROCEDURES

One way to help insure that all the appropriate regulations are followed is to use shipping and receiving procedures (see Appendix A). These procedures will also make it easier to gain NRC approval of the quality assurance plan discussed in Paragraph IV.A.

F. GENERATOR PREPARATION

1. Hardware

To avoid possible damage to the RTG's thermoelectric module, the following steps must be taken:

    a. Insure that the finned radiator assembly is bolted to the RTG's lid.

    b. Insure that the shorting plug is installed.

All RTGs will be shipped to the Air Force on steel pallets specifically designed for each model. If the RTGs are subsequently removed from these pallets, insure they are reinstalled as shown in Chapter II. Hardware attaching the brackets to the pallet should be torqued to: 120-130 foot-pounds (25E, 25F) or 270-330 foot-pounds (100F).

2. Markings

The following markings are required by 49 CFR. Letters must be at least 1/2" high.

    a. "RADIOACTIVE MATERIAL, SPECIAL FORM, N.O.S."

    b. (Gross Weight)

    c. "TYPE B"

    d. "USA/4888/B ( )" for Sentinel 25 Series RTGs

    e. "USA/5862/B ( )" for the Sentinel 100F

    f. "UN 2974", an international identification for special form material

    g. (Model Number; e.g.: "Sentinel-25F")

3. Labelling

Two "RADIOACTIVE-YELLOW III" labels are required on each RTG. They must be completed to show the radioisotope (strontium-90), curie content (as appropriate), and transport index (as appropriate) and are placed on opposite sides of the generator.

G. SHIPPING PAPERS

Certain information must be placed on shipping papers (government bill of lading) whenever hazardous cargo is shipped. In addition to the normal entries (item name, weight, cube, etc.), the following information must be included for RTGs:

    1. "Radioactive Material, Special Form, n.o.s. (Strontium-90 Titanate)"

    2. "Highway Route Controlled Quantity"

3. "UN 2974"

4. (Activity in Curies)

5. "RADIOACTIVE-YELLOW III LABEL"

6. "TRANSPORT INDEX: ____"

7. "Package Identification Number: USA/4888/B ( ) "for Sentinel 25 Series

   RTGs;" USA/5862/B ( )" for the Sentinel 100F.

8. (Appropriate certification required by 49 CFR)

NOTE: For air transport, "CARGO-ONLY AIRCRAFT" must be added to the

   above.

H. HANDLING AND TIE-DOWNS

Sentinel RTGs may be handled by fork-truck, with the forks fully engaged under
the pallet, or by an overhead hoist or crane attached to the handling sling. All ma-
terials handling equipment should have a safe working load sufficiently greater than
the weight of the RTG/pallet combination and should have been weight-tested within
the prescribed period.

If the generator is lifted from above, the handling sling should be attached to
eye bolts (see table below) which have been installed in the RTG's upper flange. (For
the Sentinel 25F and 100F, it will first be necessary to remove two of the bolts which
attach the finned radiator to the RTG's hull.)

Generator Model	Required Eyebolts
25E	7/8" Dia x 2-1/4" Lg; 7000 Lb, SWL
25F	5/8" Dia x 8" Lg; 3500 Lb, SWL
100F	5/8" Dia x 10" Lg; 3500 Lb, SWL

Sentinel RTGs should be handled with reasonable care. Their thermoelectric
modules are relatively brittle and open/short circuits can develope if the RTG is
handled roughly. RTGs should never be dropped or pulled along a surface. Forklift

and crane operators should take care to set them down gently. When transported by common carrier, air-ride trailers are advisable. Drivers should avoid rough roads whenever possible. Tie-downs should be attached as shown on Figure IV-1.
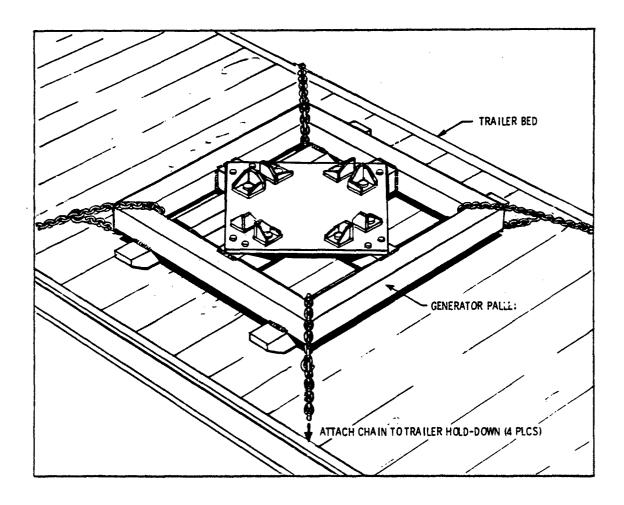
FIGURE IV-1. PALLET TIE-DOWN CONFIGURATION

V. GENERATOR INSTALLATION

The following guidelines should be used when writing installation procedures:

1.   The RTGs should be handled in accordance with the instructions provided in Chapter IV.

2.   Each RTG should be checked to make sure it is operating properly. The easiest way to do this is to measure the voltage and current at short circuit and the open circuit voltage from short circuit, calculate the associated internal resistance, and then compare these measurements and the internal resistance with values previously obtained. After an RTG has been positioned in its final location, get the proper RTG-PCU interconnecting cable (see II. E) and the RTG load box (see II. G). Then perform the following steps:

    a.   Set the load box to short circuit.

    b.   Connect the cable to the load box.

    c.   Remove the RTG's shorting plug and connect the cable to the RTG.

    d.   Wait 20-30 minutes for the RTG to re-stabilize.

    e.   Measure and record the "load" voltage (E_L) and current (I_L).

    f.   Hold the "Open Circuit" switch open for approximately three seconds, read and record E_{oc} at the end of that period, and release the switch. (A digital multimeter with a "hold" feature is ideal for this measurement.)

    g.   Disconnect the cable from the RTG and reinstall the RTG's shorting plug OR leave the RTG connected to the load box (set on short circuit) until the PCU is ready to be hooked up. NOTE: The system (RTG-RTG-PCU) connection procedure (found in the PCU Operation and Maintenance Manual) assumes a shorting plug is installed in each RTG and is written so that the last connections are made at the RTGs. However, there is no reason why the last connections can't be made at the PCU.

h. Calculate internal resistance:

$$R_i = \frac{E_{oc} - E_L}{I_L}$$

and compare all measurements and R_i with the latest values available.

3. RTG-PCU interconnecting cables should be routed to prevent chafing and sharp bends, and to minimize strain on the connectors. (Stand-offs have been provided with the Sentinel 25F and 100F RTGs to keep the cables from rubbing against their cooling fins.)

4. If the RTGs are not tested as suggested in paragraph 2, shorting plugs should not be removed until the RTG-PCU interconnecting cables have been attached to the PCU and the cables are ready to be connected to the RTGs.

VI. TROUBLE-SHOOTING

A. GENERAL

Systematic trouble-shooting procedures should be used to determine the cause of an apparent reduction in or loss of system (RTG-RTG-PCU) power. Trouble-shooting in the field is generally limited to isolating the system component which is defective. This chapter gives procedures which can be used in the field to identify faulty components.

B. POWER SUPPLY SYSTEM OR LOAD?

Disconnect the load and adjust the PCU output voltage to the nominal value given in the appropriate PCU Operation and Maintenance Manual. Allow 3-4 hours for the RTGs to stabilize. Then complete the steps contained in the PCU Operation and Maintenance Manual under "Operational Check and Adjustment." Ignore the requirement for additional stabilization time. If the PCU output voltage cannot be set at the nominal value or if the criteria for satisfactory system performance given in the PCU Operation and Maintenance Manual are not met, proceed to the next section.

C. PCU OR RTGS/CABLES?

Replace the PCU with its spare and repeat the steps taken in Section B except allow 16 hours for the RTGs to stablilze. If the results are the same, proceed to the next section. Otherwise, the original PCU is defective. PCU trouble-shooting and repairs are covered in the PCU Operation and Maintenance Manual. NOTE: Always keep the spare PCUs operating properly.

D. RTG OR CABLE?

Get the RTG load box. Set it up for loading two RTGs independently and measuring the voltage drop across each RTG's thermoelectric module (see Figures II-17 and II-18):

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1. If jumpers are connected between terminals 1 and 2, 3 and 4, 5 and 6, or 7 and 8 on Terminal Board 1, remove them.

2. Connect a shorting link between J7 and J8.

3. Connect another shorting link between J9 and J10.

Set the "Generator #1" side of the load box to 0.5 ohms (Sentinel 25 RTGs) or 1.1 ohms (Sentinel 100F), depending on which RTG model will be connected to the Generator #1 input. Do the same for the Generator #2 side. Disconnect each RTG-PCU inter-connecting cable from the PCU and connect it to the appropriate load box input. Wait 24 hours for the RTGs to stabilize. Then perform the follow steps for EACH RTG :

1. Measure and record the voltage (E_L) and current (I_L).

2. Hold the "Open Circuit" switch open for approximately three seconds, read and record E_{oc} at the end of that period. and release the switch. (A digital multimeter with a "hold" feature is ideal for this measurement.)

3. Calculate the thermoelectric module's internal resistance:

$$R_i = \frac{E_{oc} - E_L}{I_L}$$

4. Calculate the thermoelectric module's power output:

$$P = E_L I_L$$

If the power output is zero, go on to step 5 and determine if the problem is with the RTG or the cable. Otherwise, compare the power output with the values given in TES Report No. 3189 (see Chapter III of this manual) for August 1984 and October 1995. It should lie somewhere in between. Make sure the comparison is made at the same current (I_L). If the power output is less than it should be, go on the step 6. If it seems right, check out the cable for high resistance (see step 5 for acceptable cable resis-tances). If the cable is OK, the problem is high resistance in the wiring

between the RTG's thermoelectric module and its electrical connector and/or the connector itself. In this event, contact TES.

5. <u>Total Power Loss</u> - A total power loss is indicative of an open circuit condition or a direct short across the thermoelectric module. Go through the following steps to determine if the problem is with the RTG or cable:

a. Disconnect the cable from the RTG.

b. Measure and record the voltage across each set of power pins. Install the RTG's shorting plug. If either measurement is zero or near zero, the problem is with the RTG's electrical connector, interior wiring, or module and TES should be contacted. The cable should be checked in any event. Disconnect the cable from the load box and measure the following resistances:

(1) between connectors (check each power lead)

(2) between each power pin and all other pins (check each connector)

(3) between each power pin and the connector's shell (check each connector).

The first measurement should be less than 0.030 ohms. The others should be on the order of 10^9 ohms. If the cable is faulty, replace it, then plot the RTG's "equilibrium" I/V characteristic using data obtained in accordance with Appendix C. Compare the result with the measurements and predictions given in TES Report No. 3189 (see Chapter III in this manual) to see if the faulty cable resulted in a damaged thermoelectric module.

6. <u>Partial Power Loss</u> - A partial power loss may be caused by any of the following reasons: more degradation in the thermoelectric module than expected, a partial short circuit in the module, or generator gas leakage.

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If the internal resistance calculated in Step 3 is substantially different from the values given in TES Report No. 3189, then the problem is internal to the RTG. The internal resistance could either be lower (caused by a partial short) or higher (caused by extreme degredation or a broken bond(s)) than reported in TES-3189. If either of these conditions are noted, an "equilibrium" I/V characteristic should be plotted using data obtained in accordance with Appendix C and the results reported to TES.

After all tests have been completed, insure that shorting plugs have been connected to both RTGs.

APPENDIX A

RTG SHIPPING AND RECEIVING PROCEDURES

APPENDIX A

RTG SHIPPING AND RECEIVING PROCEDURES

A.   BACKGROUND

The following procedures and precautions have been written to insure compliance with applicable portions of the Code of Federal Regulations. Since local regulations may vary with each installation, compliance with those requirements must also be assured.

B.   SHIPPING AN RTG

1.   Shipping Custodian.   The custodian of the RTG at the point of origin of the shipment is designated the shipping custodian. He is responsible for making shipping arrangements and for insuring compliance with all regulations governing such shipments; these include Nuclear Regulatory Commission (NRC), Department of Transportation (DOT), Department of Defense (DOD), and U.S. Air Force regulations, as well as the local regulations of the installation that is the point of origin and the installation that is the destination.

2.   Documentation.   The following forms are involved in the shipment of an RTG. (Completed examples of the DD Form 836 and RTG Transfer Document are included at the end of this Appendix.)

a.   DD Form 1149, Requisition and Invoice/Shipping Document.   This form, when properly executed, requests that transportation arrangements be made for shipping the RTG; its function is to initiate shipping action with the local supply department. All the information DOT requires to be on shipping papers must be included on the DD1149. Preparation of this form is the responsibility of the shipping custodian. NOTE: The DD Form 1149 may not be applicable at all installations. However, the information provided on this form must be a part of any request for a bill of lading sent to the local supply department.

b.   Certificate of Compliance.   This certificate is specific to the RTG model being shipping and lists any special requirements for shipping that model. It certifies that the RTG, in its approved shipping configuration, meets all applicable packaging standards. It is the responsibility of the shipping custodian to insure that the certificate is still valid and to include a copy of the certificate and the NRC letter authorizing its use with submission of the DD Form 1149.

c.   DD Form 836, Special Instructions for Motor Vehicle Drivers.   This form is used to provide general precautions and special instructions to the driver as to the action he should take with respect to the RTG under normal conditions of transport and in case of fire, accident, breakdown, or other special conditions. Preparation of this form is the responsibility of the supply department at the point of origin. Information to be included on this form originates from the shipping custodian and must be included with the submission of the DD Form 1149.

d.   Radioisotope Thermoelectric Generator (RTG) Transfer Document.   This document is used to provide a permanent record of the radiation and contamination levels associated with the RTG and to document other aspects of the shipment.

3. **Procedures.** Procedures for shipping an RTG are divided into three time phases: long-range preparations, short-range preparations, and final preparations.

 a. **Long-Range Preparations.** These preparations are required to assure that the RTG can be transferred from the shipping custodian to the receiving custodian without legal impediment. They are accomplished in five general steps.

  (1) Check for the existence of legal impediments affecting the transportation of the RTG between the facility of origin and the receiving facility.

   (a) If the shipment is made to other than Air Force installations, verify that the receiver is eligible under NRC license or Department of Energy contract to receive the shipment, and obtain a copy of the license or other proof as allowed by 10 CFR 30.41.

   (b) If a valid NRC Certificate of Compliance exists for the RTG, determine if the certificate will still be valid at the latest date that the RTG may arrive at its destination; if the certificate will expire prior to that date, initiate action to have the certificate renewed. If the certificate includes restrictive conditions, select a transportation mode that will meet the specified conditions.

   (c) If a valid Certificate of Compliance does not exist, initiate action to obtain one.

  (2) Check for existence of legal impediments at the point of origin of the shipment; determine the nature of any local regulations and conditions which must be fulfilled prior to moving the RTG within and out of the installation. Make provisions and schedule necessary activities for accomplishing these actions prior to the shipment date. Notify the local radiation safety officer of the intent to ship the RTG.

  (3) Check for existence of legal impediments at the destination; determine from the receiving custodian the nature of any local regulations and conditions which must be fulfilled prior to moving the RTG into and within the installation. Make provisions and schedule necessary activities for accomplishing these actions.

  (4) Check the Certificate of Compliance and manufacturer's Operation and Maintenance Manual to determine the configuration(s) in which the RTG must be shipped. Inspect the RTG and shipping container (if applicable) for abnormal wear, defects, and damaged components to insure that no damage has been sustained which would significantly reduce the effectiveness of the package.

 b. **Short-Range Preparations.** These preparations are required to obtain a carrier. They are accomplished in two general steps:

  (1) Approximately 30 days prior to the desired shipping date, prepare and summit to the local supply department the DD Form 1149 or other paperwork required to secure a government bill of lading (GBL). Include the following enclosures:

   (a) NRC Certificate of Compliance for the RTG being shipped and the NRC letter authorizing its use.

(b)   DD Form 836, Special Instructions for Motor Vehicle Drivers.

Make sure the Supply Department knows that RTGs contain a "highway route controlled quantity" of radioactive material and that only certain carriers can meet the DOT requirements. Refer them to 49 CFR 177.825. Also stress that all of the information you provided on the DD 1149 (see paragraph B.2.a) must go on the GBL. Request an "exclusive-use" shipment and a "low-boy" or vented van with air-ride suspension.

(2)   When the supply department advises that the GBL has been issued:

(a)   Obtain the name, address and local phone number of the carrier and request a copy of the GBL for the shipping custodian's files.

(b)   Advise the receiving custodian of the shipping date and carrier, and determine from him the nature of recent changes, if any, in local regulations and procedures affecting receipt of the RTG. If there have been changes, take appropriate action.

(c)   Notify the local radiation safety officer of the planned shipment date.

c.   Final Preparations.   These preparations are required to permit physical loading and shipping of the RTG, performance of the required radiological safety checks, and completion of documentation. They are accomplished in three general time-phased steps:

(1)   Five working days prior to the shipping date:

(a)   Make arrangements for the necessary materials handling equipment.

(b)   Insure that the RTG is properly configured and prepared for transport.

(c)   Insure that all radiation warning labels required by NRC and DOT are legible and securely attached to the RTG.

(d)   Insure that markings required by DOT are legible.

(e)   Set aside four RADIOACTIVE placards (per vehicle) for the carrier.   (Special placards are required for "highway route controlled quantities.")

(f)   Examine the DD Form 836 to insure that the special instructions for the vehicle driver are complete. If they are incomplete, or erroneous, arrange with the local supply department to complete or revise them as necessary.

(2)   Two working days prior to the shipping date:

(a)   Determine the approximate time that the carrier will arrive.

(b)　Notify the local radiation safety officer of the expected arrival time.

(c)　Notify the materials handling equipment operators of the expected arrival time.

(d)　Prepare five copies of the RTG Transfer Document insofar as available information permits.

(e)　Make arrangements for health physics support.

(3)　On the shipping date:

(a)　When the carrier arrives, have him directed to the RTG loading area. Request materials handling equipment.

(b)　Supervise RTG leak tests.

(c)　Supervise contamination tests.

(d)　Supervise radiation surveys.

(e)　Monitor the loading of the RTG. Insure that the RTG is handled and tied-down in accordance with the manufacturer's requirements.

(f)　Complete the remainder of the items in Sections 1 and 2 of the RTG Transfer Document and sign all the copies. Retain the original and one copy and provide three copies to the driver. Instruct the driver to deliver the three copies to the receiving custodian.

(g)　Insure that RADIOACTIVE placards are displayed as required by 49 CFR.

(h)　Insure that the driver has a copy of the NRC Certificate of Compliance and the NRC letter authorizing its use.

(i)　Review DD Form 836 with the driver to assure that he understands the instructions. Determine his estimated date and time of arrival at the destination, and release the vehicle.

(j)　Notify the receiving custodian of the following:

1　Carrier's name.

2　Government bill of lading number.

3　Shipment contents.

4　Time of departure of shipment.

5　Estimated date and time of arrival of shipment.

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C. RECEIVING AN RTG

1. **Receiving Custodian.** The custodian of the RTG at the destination of the shipment is designated as the receiving custodian. He is responsible for making all necessary local arrangements for receipt of the RTG, for compliance with all regulations governing the RTG shipment, and for compliance with all regulations governing the storage, local transportation, installation, and operation of the RTG while it is in his custodianship.

2. **Documentation.** Only one item is of direct concern to the receiving custodian: the RTG Transfer Document.

3. **Procedures.** Procedures for receiving an RTG are also divided into three time phases: long-range preparations, short-range preparations, and final preparations.

    a. **Long-Range Preparations.** These preparations are required to assure that the receiving custodian can physically receive the RTG without legal impediment: Check for existence of legal impediments at the receiving facility; determine the nature of any local regulations and conditions which must be fulfilled prior to moving the RTG into and within the facility. Make provisions and schedule necessary activities for accomplishing these actions. Notify the shipping custodian of any of the regulations or conditions which may affect his preparations for shipment of the RTG.

    b. **Short-Range Preparations.** These preparations are required to handle any last minute changes affecting physical movement of the RTG into the receiving facility. When advised by the shipping custodian as to the RTG shipping date and carrier, determine the nature of recent changes, if any, in local regulations and procedures affecting receipt of the RTG. If there have been changes, provide necessary information to the shipping custodian. Notify the local Radiation Safety Officer.

    c. **Final Preparations.** These preparations are required to permit physical reception and unloading of the RTG, performance of the required radiological safety checks, and completion of documentation. These preparations are accomplished in two general time-phased steps.

        (1) Two working days prior to the scheduled arrival date:

            (a) Make arrangements for the necessary materials handling equipment.

            (b) Make arrangements for health physics support.

        (2) On the arrival date, upon receipt of notification that the carrier has arrived.

            (a) Request delivery of the materials handling equipment.

            (b) Upon arrival of the carrier at the RTG unloading area, obtain from the driver the shipment documentation (GBL and RTG Transfer Document (3 copies)).

            (c) Supervise vehicle radiation surveys.

(d)   Supervise vehicle contamination tests.

(e)   Supervise RTG radiation surveys.

(f)   Supervise RTG leak tests.

(g)   Monitor the unloading of the RTG. Insure that the package is handled in accordance with the manufacturers recommendations. Inspect the RTG for evidence of physical damage. If any damage is evident, made a notation on the GBL of the nature and apparent extent of the damage.

(h)   Complete the remainder of the items in Section 3 of the RTG Transfer Document and sign all copies.

1   Provide the carrier one copy.

2   Retain one copy.

3   Mail one copy to the shipping custodian.

(i)   By phone, notify the shipping custodian of the following:

1   Time shipment arrived.

2   General condition of RTG and related equipment.

SPECIAL INSTRUCTIONS FOR MOTOR VEHICLE DRIVERS

DATE

TO: *(Carrier's Name and Trailer Number)*

FROM: *(Installation Issuing Instructions)*
Naval Nuclear Power Unit
Port Hueneme, CA 93043

BILL OF LADING NUMBER

THIS TRUCK IS LOADED WITH *(Commodity description)* EXAMPLE:
One URIPS-8 Radioisotope Thermoelectric Generator (RTG)
containing 50,000 Curies (max) of Strontium-90 Titanate
biologically shielded with Uranium (depleted).

TYPE PLACARDS REQUIRED
RADIOACTIVE

IN CASE OF FIRE

1. If any part of the vehicle outside of actual contents catches fire, take vehicle to a clear or uninhabited area, if practicable, and/or attempt to put fire out immediately with hand extinguishers or other available means. If practicable, ask someone to notify the fire department. Call to the attention of fire or police personnel at the scene of the fire the information on this form.

2. Fires may be fought until the flames reach the cargo, at which time firemen and other personnel should be withdrawn to a safe distance, as noted in 5 and 6 below.

3. If in convoy, other trucks proceed to safe distance.

4. Water may be used on this cargo [X] Yes [ ] No
(See Other Specific Precautions or Instructions below)

5. Firemen should not approach closer than 10 feet* from the fire when the fire has reached the cargo. *(See Other Specific Precautions or Instructions below)*

6. Public should not approach closer than 100 feet* from fire.

7. As soon as practical, notify the nearest military installation.

IN CASE OF ACCIDENT

1. Set brake and block vehicle to prevent movement.

2. Post flags by day, and red electric lanterns or reflectors by night, warning traffic approaching from each direction.

3. Call for ambulance, if necessary.

4. Notify nearest police.

5. Notify nearest military installation if cargo is damaged.

ADDITIONAL NOTIFICATION REQUIRED *(By phone or wire as soon as possible)*
Naval Nuclear Power Unit
Port Hueneme, CA 93043
Tel: (805) 982-5323

IN CASE OF BREAKDOWN

1. Do not attempt to tow loaded vehicle.

2. Post flags by day and red electric lanterns by night, warning traffic from each direction.

GENERAL PRECAUTIONS

1. While operating over public roads, keep at least 300 feet from trucks loaded with explosives or other dangerous articles; a greater minimum distance must be maintained if required by state or municipal regulations.

2. Protect the public from the hazards of the cargo.

3. Do not allow smoking or use of matches or lighters in or near the vehicle.

4. Obey all state and local traffic regulations.

5. Do not exceed posted speed limits.

6. Stop at all railroad crossings.

7. Use designated routes. Whenever possible, avoid congested residential or business areas.

8. Do not permit unauthorized persons to ride on vehicles.

9. At other than carrier rest stops or interchange points, select safe parking space at stopping locations designated by the carrier. Vehicles carrying explosives should not group together at these stopping locations.

OTHER SPECIFIC PRECAUTIONS OR INSTRUCTIONS

1. In the event of loss, theft, fire, accident or any other unusual incident concerning the radioisotope thermoelectric generator, the Naval Nuclear Power Unit shall be notified immediately; phone (805) 982-5323.

2. <u>Progress Reports</u>. At intervals of 8-10 hours, notify dispatcher of location and status.

3. Once secured the RTG(s) should not be moved until the ultimate destination is reached. Nothing should be loaded on top or within one foot of the shipping cage/container.

4. Shipment must arrive at_____between _____and _____. Contact_____ upon arrival. <u>Example:</u> Shipment must arrive NAS Point Mugu between 8 AM and 2 PM. Driver shall stop at Gate #3 and notify Security using the phone at the gate that he is carrying a radioactive shipment and request that the Radiation Safety Officer (x7607) or 7142) or Naval Nuclear Power Unit (63) 5323 be notified. The driver shall then wait at the gate until a radiological survey has been completed.

These instructions must be transferred to each subsequent driver for turn-in at final destination. If more than 3 drivers are involved, the additional signatures should be made on an extra sheet and attached hereto.	SIGNATURE OF SHIPPER REPRESENTATIVE	SIGNATURE OF FIRST DRIVER
	SIGNATURE OF SECOND DRIVER	SIGNATURE OF THIRD DRIVER

* The distances shown are minimum; greater distances should be used whenever possible.

DD FORM **836** 1 MAY 71   REPLACES EDITION OF 1 JUN 66, WHICH MAY BE USED.

RADIOISOTOPE THERMOELECTRIC GENERATOR (RTG) TRANSFER DOCUMENT

.1131G/1 (1-78)

1. PACKAGE DESCRIPTION

RTG	GCC	ISOTOPE	ACTIVITY*	PACKAGE DESCRIPTION	DIMENSIONS	VOLUME	WEIGHT
11	4888	Sr-90	76,788	Sentinel 25E on pallet	46"Lx46"Wx52"H	64cf	4450#
12	4888	Sr-90	79,051	Sentinel 25E on pallet	46"Lx46"Wx52"H	64cf	4450#
13	4888	Sr-90	77,461	Sentinel 25E on pallet	46"Lx46"Wx52"H	64cf	4450#
32	4888	Sr-90	81,714	Sentinel 25E on pallet	51"Lx43"Wx49"H	62cf	4450#
41	5862	Sr-90	260,555	Sentinel 100F on pallet	51"Lx43"Wx54"H	69cf	3000#

* as of 30 June 1981

2. SHIPPER'S DATA

A. NAME AND ADDRESS
Naval Energy and Environmental Support Activity
Port Hueneme, CA 93043

B. NRC LICENSE NO.
04-07316-03

C. RSR NO.
N/A

D. CARRIER
American Farm Lines

E. BOL NO.
53929726

F. PACKAGE DATA

RTG	SURFACE ER	ER AT 1m,	CONTAMINATION ALPHA	BETA	RTG LEAK TEST RESULTS* ALPHA	BETA
11	50	3.2	--	--	--	<7.8
12	45	3	--	--	--	<5.1
13	50	3.3	--	--	--	2.7+8.3
32	50	3.5	--	--	--	6.2+7.2
41	70	4	--	--	--	<9.3

* picocuries (95% CL)

G. SHIPPING VEHICLE DATA

CAB ER	SURFACE ER	VEHICLE CONTAMINATION ALPHA	BETA
0.25	4.5	N/A	<113dpm/100cm²

DATE SHIPPED
7-21-81

SIGNATURE
(signature)

3. RECEIVER'S DATA

A. NAME AND ADDRESS
1155th Technical Operations Squadron (LGE)
McClellan AFB, CA 95652

B. NRC LICENSE NO.
04-09951-03

C. RSR NO.
N/A

F. PACKAGE DATA

RTG	SURFACE ER	ER AT 1m,	CONTAMINATION ALPHA	BETA	RTG LEAK TEST RESULTS* ALPHA	BETA
11	70mR/hr		--	--	--	1.3
12	65mR/hr		--	--	--	8.2
13	60mR/hr		--	--	--	1.3
32	70mR/hr		--	--	--	4.1
41	90mR/hr		--	--	--	0.9

* picocuries

G. SHIPPING VEHICLE DATA

CAB ER	SURFACE ER	VEHICLE CONTAMINATION ALPHA	BETA
0.40 mR/hr	0.05 mR/hr all surfaces	NA	

DATE RECEIVED
22 Jul., 81

H. SIGNATURE
Kenneth M. Partridge (signature)

APPENDIX B

RADIOLOGICAL SAFETY

APPENDIX B

RADIOLOGICAL SAFETY

1. Introduction

The fundamental prerequisite for use of a radioisotope thermoelectric generator is assurance that it will present no undue hazard to the health and safety of user personnel as well as the general populace. The degree of attainment of these objectives is achieved by establishing specific safety design guides, employing sound engineering and manufacturing technology and performing rigorous analyses of the postulated hazards resulting from both routine and accidental occurrences involving a generator.

2. Objectives

The Sentinel series of RTGs is designed to provide a maximum amount of flexibility and convenience with a minimum amount of effort on the part of the user. Simple precautions such as minimizing the time a person spends in the vicinity of an RTG and maximizing the distance between a person and an RTG will insure that doses are maintained as low as reasonably achievable. These precautions should be reflected in any procedure involving the handling, installation, or use of an RTG.

3. Characteristic Exposure Rates

Each RTG which will be implanted at Burnt Mountain produces slightly different radiation levels. The maximum exposure rate at the housing varies between 50 and 80 mR/hr and the maximum exposure rate at one meter from the housing varies between 4 and 6 mR/hr. There are no abrupt changes in these rates either in tne axial or circumferential directions.

4. Radiation Protection Standards

Annex 1 to this appendix contains recommended radiation protection standards. These standards have been adopted by cther RTG users and are included here to

illustrate what has been acceptable to the Nuclear Regulatory Commission in the past. Obviously the Air Force must abide by the terms of its existing NRC Materials License but if a change is contemplated, these guidelines should serve as a useful reference.

5.   Radiation Surveys, Contamination Tests, and Leak Tests

The minimum requirements for radiation surveys, contamination tests, and leak tests are also given in Annex 1 to this Appendix. Procedrues for conducting these surveys and tests with an AN/PDR-27 Radiacmeter are provided in Annex 2.

6.   Operating and Emergency Procedures

Operating procedures covering the handling and installation of RTGs should be written to insure that doses are maintained as low as reasonably achievable and to insure that the RTGs are not damaged. These procedures need not contain extraordinary radiation safety precautions because the exposure rates are characteristically low and handling is normally straightforward. Their real value lies in the added assurance that the RTG's thermoelectric module will not be damaged.

Emergency procedures are a required part of any NRC Materials License Application. Annex 3 to this Appendix contains a sample emergency plan which has been used in the past to develope emergency plans for other projects involving RTGs.

ANNEX 1

RECOMMENDED RADIATION PROTECTION STANDARDS

A. Definitions

1. **High Radiation Area.** Any area in which there exists radiation at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirem.

2. **Occupationally Exposed Personnel.** Personnel who are routinely or occasionally assigned to duties (e.g., RTG users) resulting in exposure to the radiation emitted from an RTG.

3. **Radiation Area.** Any area in which there exists radiation at such levels that a major portion of the body could receive in any seven consecutive days a dose in excess of 100 millirem.

4. **Radioactive Materials Area.** Any area or room in which an RTG is used or stored.

5. **Restricted Area.** Any area to which access is controlled by the Installation Commander for the purpose of protecting individuals from exposure to the radiation emitted from an RTG.

B. Permissible Doses, Levels and Concentrations

1. **Dose Limits for Occupational Exposures.** Occupationally exposed personnel shall not be permitted to receive in any period of one calendar quarter a dose in excess of that specified in the following table:

REMS PER CALENDAR QUARTER

a.	Whole body; head and trunk; active blood forming organs; lens of eyes; or gonads	1-1/4
b.	Hands and forearms; feet and ankles	18-3/4
c.	Skin of whole body	7-1/2

2. **Dose Limits for Members of the General Public and Underage Personnel.** No individual under 18 years of age or member of the general public shall be permitted to receive in any period of one calendar quarter a dose in excess of 10 percent of the limits specified in the above table. The "general public" includes non-occupationally exposed personnel such as visitors, messengers, riggers, equipment operators, and other persons whose exposure to RTGs is truly sporadic and who are not otherwise involved with radioactive materials or equipment producing ionizing radiation.

3. **Radiation Levels in Unrestricted Areas.** RTGs shall not be used, stored, or transferred in a manner that will cause any individual, if continually present in an unrestricted area, to receive a dose in excess of 100 millirem in any seven consecutive days.

4. <u>Permissible Levels of Surface Contamination.</u>   An object or surface is considered to be contaminated when the loose surface contamination exceeds 1000 disintegrations per minute of beta-gamma activity over an area of 100 cm^2.

5. <u>Permissible Levels for RTG Leak Tests.</u>   An RTG will be treated as though its fuel capsule is leaking if more than 0.005 microcuries of activity are detected by the following leak test procedure:

a.   On one side of a filter paper disc or cloth swipe (2.5-5 cm diameter), identify the RTG to be leak tested by writing: "LEAK TEST, RTG (RTG S/N), (DATE)."

b.   Using the unnumbered side of the disc or swipe, wipe along the entire seam between the RTG's lid and its housing or along the nearest accessible surface to that seam.   Also wipe along the seam between the power receptacle and the housing.

c.   Analyze the smear to determine the amount of activity removed.

C.   <u>Radiation Surveys</u>

1.   Radiation surveys shall be made:

a.   Whenever an RTG is received, but prior to offloading from the shipping vehicle.

b.   Whenever an RTG is initially placed in storage or use (to document levels in unrestricted areas).

c.   After an RTG is loaded on a shipping vehicle, but prior to shipment.

d.   Twice annually, while in storage or use, except for those RTGs located in remote, uninhabited areas which are visited only when operational necessity requires.   In this case, a radiation survey will be made whenever the RTG site is visited.

2.   For the surveys required by paragraphs C. 1. b and d above, a sketch will be made showing the location of caution signs, and other physical features in the vicinity of the RTGs such as walls, doors, etc.   The type of instrument employed and its calibration date will also be included.

D.   <u>Contamination Tests.</u>   Shipping vehicles shall be tested for contamination before RTGs are onloaded or offloaded.   In the case of receipts, swipes should also be taken after all RTGs are offloaded to document that the vehicle is free of contamination and can be released.   Shipping cages, if used, shall be tested for contamination before an RTG is loaded (unloaded) on (from) a shipping vehicle.

E.   Leak Tests.   Each RTG shall be leak tested at the time of receipt (before off-loading) and shipment (before onloading).

F.   Personnel Monitoring

1.   Requirements.   All occupationally exposed personnel who enter a radiation area shall wear a film badge or thermoouminescent dosimeter (TLD).   All occupationally exposed personnel entering a high radiation area shall also wear a pocket dosimeter.   Non-occupationally exposed personnel who enter a radiation area may be issued a pocket dosimeter in lieu of a film badge or TLD.   Groups of visitors may utilize a single film badge, TLD, or pocket dosimeter, as appropriate.   A logbook shall be maintained for pocket dosimeter readings.

2.   Control of Personnel Monitoring Devices

a.   Issuance.   Film badges, pocket dosimeters, and TLDs will be procured and issued in accordance with (insert the appropriate USAF technical order or publication).

b.   Storage.   When not in use, personnel monitoring devices shall be kept in a low background area which is readily accessible.   Control badges/TLDs shall be stored at the same location.

c.   Use.   Film badges, pocket dosimeters, and TLDs shall be used in accordance with (insert the appropriate USAF technical order or publication).   They shall be worn on that part of the body expected to receive the greatest exposure.

d.   Processing.   Film badges and TLDs will be processed in accordance with (insert the appropriate USAF technical order or publication).

G.   Caution Signs and Labels

1.   Radiation Area Signs.   Each radiation area will be conspicuously posted with a sign or signs as required by 10 CFR 20.203(b).

2.   Radioactive Materials Area Signs.   Each area or room in which an RTG is stored or used shall be conspicuously posted with a sign or signs as required by 10 CFR 20.203(e).

3.   Labels.   Each RTG shall bear a durable, clearly visible label identifying its radioactive contents by isotope, activity, and date of activity determination.   It shall also contain the radiation caution symbol and the words "CAUTION, RADIO-ACTIVE MATERIAL" OR "DANGER, RADIOACTIVE MATERIAL."

H.   Radiological Safety Training.   All personnel who use or work with RTGs will receive a complete orientation and indoctrination in radiological safety.   All RTG users will be made aware of the potential radiological hazards involved in their work; radiological safeguards, procedures, and regulations pertaining to RTGs; and their responsibilities with regard to radiological safety.

I.   Records and Reports

1. <u>Personnel Exposure Records.</u> Radiation exposure data for occupationally exposed personnel shall be recorded on Form DD 1141, Record of Occupational Exposure to Ionizing Radiation. This form shall be maintained in the individual's medical record in accordance with (insert the appropriate USAF technical order or publication).

2. <u>Radiation Surveys, Contamination Tests, Leak Tests</u>

   a. Radiation surveys, contamination tests, and leak tests associated with the shipment and receipt of RTGs shall be recorded on an RTG Transfer Document (Attachment 1) whenever required by paragraphs C, D, and E.

   b. Radiation surveys of RTGs in storage or use shall be recorded as required by paragraph C. 2.

RADIOISOTOPE THERMOELECTRIC GENERATOR (RTG) TRANSFER DOCUMENT

(See Instructions on Back)

1. PACKAGE DESCRIPTION

RTG	COC	ISOTOPE	ACTIVITY	PACKAGE DESCRIPTION	DIMENSIONS	VOLUME	WEIGHT

2. SHIPPER'S DATA

A. NAME AND ADDRESS

B. NRC LICENSE NO.

C. CARRIER

D. BOL NO.

E. PACKAGE DATA

RTG	SURFACE ER	ER AT 1m.	CONTAMINATION BETA	RTG LEAK TEST RESULTS BETA

F. SHIPPING VEHICLE DATA

CAB ER	SURFACE ER	VEHICLE CONTAMINATION ALPHA	BETA

G. SIGNATURE

DATE SHIPPED

3. RECEIVER'S DATA

A. NAME AND ADDRESS

B. NRC LICENSE NO.

E. PACKAGE DATA

RTG	SURFACE ER	ER AT 1m.	CONTAMINATION BETA	RTG LEAK TEST RESULTS BETA

F. SHIPPING VEHICLE DATA

CAB ER	SURFACE ER	VEHICLE CONTAMINATION ALPHA	BETA

G. SIGNATURE

DATE RECIEVED

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INSTRUCTIONS FOR COMPLETION

1. PACKAGE DESCRIPTION:

RTG – ENTER THE RTG SERIAL NUMBER.

COC (CERTIFICATE OF COMPLIANCE) – ENTER APPLICABLE COC NUMBER FOR THE RTG.

ISOTOPE – ENTER THE SYMBOL FOR THE PRINCIPLE RADIOISOTOPE PRESENT IN THE RTG.

ACTIVITY – ENTER THE QUANTITY OF RADIOACTIVITY (IN CURIES) IN THE RTG AS OF THE DATE SHIPPED.

PACKAGE DESCRIPTION – DESCRIBE HOW THE RTG IS BEING SHIPPED; e.g., RTG ON PALLET, RTG IN CAGE ON PALLET.

DIMENSIONS – ENTER THE LARGEST DIMENSIONS OF THE PACKAGE.

VOLUME – ENTER THE VOLUME BASED ON THE LARGEST DIMENSIONS OF THE PACKAGE.

WEIGHT – ENTER THE WEIGHT OF THE PACKAGE.

2, 3. SHIPPING AND RECEIVING DATA:

2A, 3A. NAME AND ADDRESS – ENTER THE TITLE OF THE COMMAND OR NAME OF THE AGENCY SHIPPING/RECEIVING THE RTG(s) AND ITS ADDRESS.

2B, 3B. NRC LICENSE NO. – ENTER THE SHIPPER'S/RECEIVER'S NRC LICENSE NUMBER.

2C. CARRIER – ENTER THE CARRIER's NAME.

2D. BOL NO. – ENTER THE BOL (BILL OF LADING) NUMBER.

2E, 3E. PACKAGE DATA:

RTG – ENTER THE ASSIGNED RTG SERIAL NUMBER.

SURFACE ER – ENTER THE MAXIMUM EXPOSURE RATE (ER) IN mR/hR, AT THE SURFACE OF THE CAGE, IF THERE IS NO CAGE, ENTER THE MAXIMUM ER AT SURFACE OF THE RTG.

ER AT 1m. – ENTER THE MAXIMUM EXPOSURE RATE (ER), IN mR/hR, ONE METER FROM THE SURFACE OF THE CAGE. IF THERE IS NO CAGE, ENTER THE MAXIMUM ER ONE METER FROM THE SURFACE OF THE RTG.

CONTAMINATION (APPLICABLE ONLY IF A CAGE IS USED) – ENTER THE QUANTITY OF BETA CONTAMINATION IN DISINTEGRATIONS PER MINUTE, REMOVED FROM APPROXIMATELY 100 cm^2 OF THE EXTERNAL SURFACE OF THE SHIPPING CAGE.

RTG LEAK TEST RESULTS – ENTER THE QUANTITY OF BETA ACTIVITY, IN MICROCURIES, REMOVED FROM THE EXTERIOR OF THE RTG DURING LEAK TESTING.

2G, 3G. SHIPPING VEHICLE DATA:

CAB ER – ENTER THE MAXIMUM EXPOSURE RATE (ER) IN mR/hR, IN THE CAB OR PASSENGER AREA OF THE SHIPPING VEHICLE.

SURFACE ER – ENTER THE MAXIMUM EXPOSURE RATE (ER) IN mR/hR, AT THE SURFACE (REAL OR IMAGINARY) OF THE SHIPPING VEHICLE.

VEHICLE CONTAMINATION – ENTER THE QUANTITY OF ALPHA OR BETA PARTICLE CONTAMINATION, IN DISINTEGRA- TIONS PER MINUTE, REMOVED FROM APPROXIMATELY 100 cm^2 OF THE VEHICLE'S SURFACE WHERE THE RTG(s) WILL BE/WERE PLACED.

2H, 3H. SIGNATURE AND DATE SHIPPED/RECEIVED – THE RTG CUSTODIAN OR HIS ALTERNATE SHOULD SIGN HERE AND ENTER THE DATE THE RTG IS SHIPPED/RECEIVED.

ANNEX 2

PROCEDURES FOR RADIATION SURVEYS,
CONTAMINATION TESTS AND LEAK TESTS
USING THE AN/PDR-27 RADIACMETER

1.   Introduction.   The purpose of this Annex is to provide RTG custodians and users with instructions for making radiation surveys and conducting contamination and leak tests using the AN/PDR-27 Radiacmeter. It is not intended that an AN/PDR-27 be used routinely for the latter tests since the proper counting equipment should be available whenever an RTG is shipped or received. However, situations may arise after an RTG is implanted when it would be desirable to determine if contamination is present and in most cases only an AN/PDR-27 is available.

2.   Definitions

    a.   Radiation Survey.   A survey taken to determine the radiation levels at the surface of and at various points in space around an RTG.

    b.   Contamination Test.   A test performed to measure the quantity of loose surface contamination present on such items as RTG shipping cages and beds of shipping vehicles.

    c.   Leak Test.   A test performed to measure Sr-90 leakage from RTGs.

3.   AN/PDR-27 Description.   The AN/PDR-27 radiacmeter is a portable, battery operated radiation detector and indicator capable of measuring up to 500 mR/hr of gamma radiation and detecting the presence of beta contamination. The principle components of the radiacmeter (Figure 1) are:

    a.   Indicating Meter.   The indicating meter is placed behind a sealed glass window for waterproofing. It has four direct reading scales which are mechanically coupled to the range switch so that the scale corresponding to the switch position is presented and no x1, x10, etc., calculations are necessary.

    b.   Range Switch.   The range switch permits selection of the following indicating meter ranges: 0 to 0.5 mR/hr, 0 to 5 mR/hr, 0 to 50 mR/hr, and 0 to 500 mR/hr plus a battery check position and the "off" position.

    c.   High Range Probe.   The small probe of the radiacmeter is the high range probe. It is activated when the range switch is set at 50 mR/hr or 500 mR/hr.

    d.   Low Range Probe.   The large probe of the radiacmeter is the low range probe. It is activated when the range is set at .5 mR/hr or 5 mR/hr.

    e.   Beta Shield.   The beta shield is a cover which is normally placed over the end of the low range probe, but swung aside when beta detection is desired.

4.   AN/PDR-27 Operation (General Instructions)

    a.   Turn the range switch (Figure 1) to BAT COND and observe the meter indication. If the pointer rests at the right of the center line in the area marked BATTERY on the scale, the batteries are in operating condition. If the pointer is to
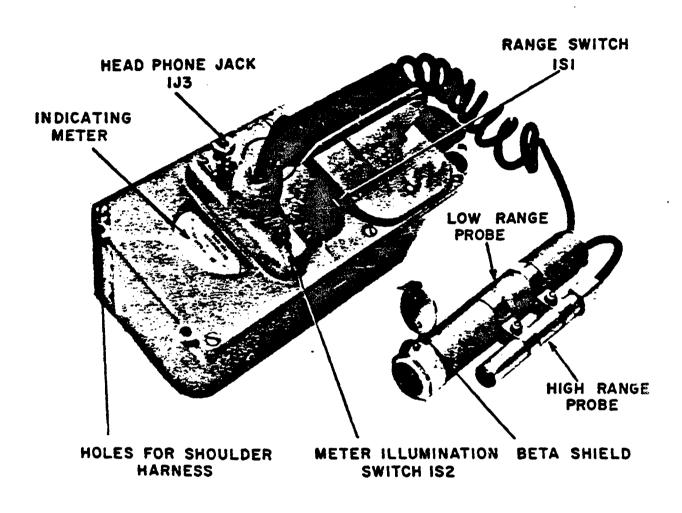
HEAD PHONE JACK
1J3

RANGE SWITCH
1S1

INDICATING
METER

LOW RANGE
PROBE

HIGH RANGE
PROBE

HOLES FOR SHOULDER
HARNESS

METER ILLUMINATION
SWITCH 1S2

BETA SHIELD

FIGURE 1.   RADIACMETER AN/PDR-27R

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the left of the center line, the batteries are exhausted. Replace all batteries in the radiacmeter as follows (Figure 2):

(1) Fully loosen the one captive screw securing the front of the handle to the panel where the probe's wire enters the case. Then loosen the two outer screws securing the cover of the battery compartment to the panel. Lift the handle which removes the cover together with the battery holder top.

(2) Insert the batteries in the battery compartment, observing the polarities indicated on the insulator at the bottom of the compartment.

(3) Replace the battery holder top and cover, observing that the rubber bumpers are lined up with the spaces at the center and tighten the two cover attaching screws. Screws must be tightened equally, or the rubber gasket may be damaged. Tighten the screw at the front end of the handle.

b. Remove the probe unit (high and low range probe assembly) from its storage location and position the unit as follows: If the range switch is set at .5 mR/hr or 5 mR/hr, aligh the unit such that the side of the low range probe (large probe) is nearest the RTG. If the range switch is set at 50 mR/hr or 500 mR/hr, hold the unit such that the side of the high range probe (small probe) is nearest the RTG.

c. Turn the range switch to a lower (more sensitive) range whenever the indicating meter reading is less than 10 percent of full scale (five divisions); turn it to a higher (less sensitive) range if the meter pointer approaches the high end of the scale.

d. Stop the radiacmeter by turning the range selector switch to OFF.

5. Radiation Survey Procedures

a. Prior to making a survey, the most recent radiation survey should be studied to determine the radiation levels previously seen at various distances from the RTG. Take this survey with you. It will permit you to determine if abnormal radiation levels exist. A sketch of the RTG and prominent items which surround it should also be made ahead of time. This will facilitate data recording. Further, the serial number and calibration date of the AN/PDR-27 and the name of the individual who is taking the survey must be recorded.

b. Under abnormal conditions (e.g., RTG shielding cracked) relatively high radiation levels may be encountered. Normally, the maximum exposure rate at one meter from a single RTG is less than 10 mR/hr and the maximum exposure rate at the surface of an RTG is less than 200 mR/hr. If radiation levels substantially above these values are encountered, refer to the emergency plan and initiate the actions specified for impact accidents. (You may wish to try a second instrument first!)

c. When approaching the RTG to make a radiation survey, start with the range switch set at the highest scale (500 mR/hr). Hold the meter in one hand with the probe unit in the other hand as follows: Grasp the large probe keeping the side of the small probe closest to the RTG in front of your body and about three feet from the ground.
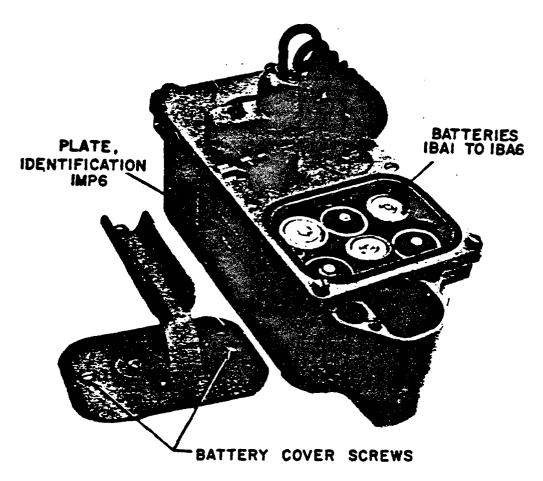
PLATE,
IDENTIFICATION
IMP6

BATTERIES
IBAI TO IBA6

BATTERY COVER SCREWS

FIGURE 2. RADIACMETER WITH BATTERY COVER REMOVED

d.   Move towards the RTG slowly, stopping every few feet to read the meter. If the meter's pointer is still on the far left of the scale when you are approximately 15 feet from the RTG, select the proper setting of the range switch in accordance with paragraph 4. c above. It will probably be the 0.5 mR/hr or 5 mR/hr scale; if so, reposition the probe unit so that you are holding it by the small probe with the side of the large probe nearest the RTG.

e.   Proceed toward the RTG and be sure to monitor the indicating meter. When the meter pointer nears the top end of the .5 mR/hr range, select the 5 mR/hr range scale. Continue toward the RTG slowly and compare existing radiation levels with those obtained previously. Note any differences.

f.   When you are approximately six feet from the RTG, lower the probe unit until the highest reading on the indicating meter is displayed. This will locate the center of the fuel capsule and will always be the point of maximum intensity under normal conditions. Proceed toward the surface of the RTG and when it becomes necessary to increase the range scale on the meter be sure to reposition the probe unit in your hand as explained in paragraph 4. b.

g.   Now conduct the radiation survey and record the results. Start by surveying the hull of the RTG. Move the small probe slowly up and down its surface (making contact with the surface) until the maximum reading is obtained. Record that reading. Repeat this step every 90 degrees around the hull. Next, step back and establish the .6 mR/hr line (radiation area perimeter). Indicate on your sketch the location of this line relative to the RTG. Additionally, if physical barriers such as a fence or the walls of a room or other structure surround the RTG, record the radiation levels at various points along these barriers (outside surface of walls). And remember, when the range is set at .5 mR/hr, the large probe should be positioned closest to the RTG with the probe unit held by the small probe.

6.   Contamination Test Procedures.   Contamination tests will be conducted in the following manner:

a.   The object or surface to be tested will be sketched for identification of specific areas which are to be wiped or "smeared."

b.   Prior to smearing a particular area, number one side of a 2.5-5 cm diameter filter paper disc or cloth swipe. Write the same number on the sketch where the specific area to be smeared is located. With your index and middle finger behind the disc, smear the unnumbered side of the disc over the area using moderate pressure, trying to cover approximately 100 cm^2 (4" x 4").

c.   Place the disc or swipe in an envelope.

d.   Repeat steps (b) and (c) until all areas of interest are smeared.

e.   Take the disc(s) or swipe(s) and an AN/PDR-27 to an area where the background radiation level is as low as possible. Remove the beta shield, set the probe unit in its holder as shown in Figure 3, set the range switch at 0.5 mRem/hr and read the background radiation level. Then place the disc or swipe under the large probe (beta shield open) and observe the meter reading. This will give a gross indication of contamination. If anything above background is indicated on the meter, smear the surface again and repeat the above procedure. If the meter reading still
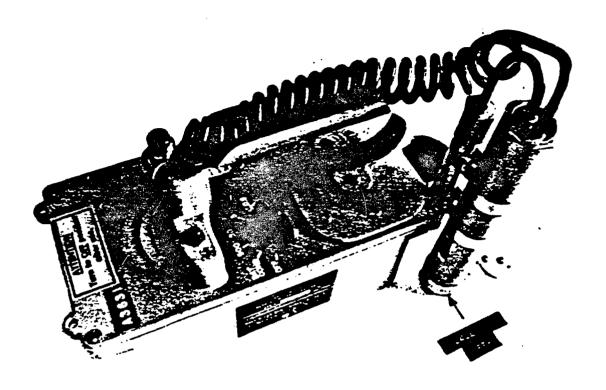
FIGURE 3. RADIACMETER CONFIGURATION FOR
ANALYZING CONTAMINATION SMEARS

exceeds the background reading, assume that the surface is contaminated and initiate
the procedures set forth in the emergency plan for dealing with contaminated areas.
If this is not the case, place the disc(s) or swipe(s) in an envelope along with the sketch
of the object smeared, the date the test was made, and the name of the individual who
made the test and mail to _____ for
analysis.

7.   Leak Test Procedure.   Leak tests of RTGs will be conducted in the following
manner:

        a.   On one side of a 2.5-5 cm diameter filter paper disc or cloth swipe,
identify the RTG to be leak tested by writing: LEAK TEST, RTG (RTG Serial Number),
(DATE).

        b.   Using the unnumbered side of the disc or swipe, wipe the entire seam
between the RTG's lid and its housing or along the nearest accessible surface to the
seam.   Then take the same disc or swipe and wipe around the seam between the power
receptacle and the RTG's hull. Use moderate pressure.

c.   Take the disc and an AN/PDR-27 to an area where the background radiation level is as low as possible. Remove the beta shield, set the probe unit in its holder as shown in Figure 3, set the range switch at 0.5 mR/hr, and read the background radiation level. Then place the disc under the large probe (beta shield open) and observe the meter reading. This will give a gross indication of leakage. If anything above background is indicated on the meter, smear the seams again and repeat the the above procedure. If the meter reading still exceeds the background reading, the RTG will be treated as if it is leaking and the emergency plan will be implemented. If this is not the case, place the disc in an envelope along with the date that the test was made and the name of the individual who conducted the test and mail it to _____
_____ for analysis.

ANNEX 3

SAMPLE EMERGENCY PLAN

FOR

RADIOISOTOPE THERMOELECTRIC GENERATORS

Annex 3
Appendix B

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

EMERGENCY PLAN

References: (a) (Insert appropriate USAF technical orders or publications)
            (b)

1. **Purpose and Scope**

This plan describes the actions to be taken and the procedures to be followed in the
event of an emergency involving the radioisotope thermoelectric generators assigned
to (enter your activity's name)   .

2. **General**

    a. **Description of Project.** (Optional)

    b. **Description of RTGs** (Briefly describe the RTGs and include normal dose
rates on contact and at one meter.)

    c. **Definitions.** An **emergency** involving a radioisotope thermoelectric gen-
erator (RTG) is defined as any event which potentially constitutes a radiological acci-
dent such as fire, collision, or dropping of the generator so as to do visible external
damage, or an event which can be interpreted to be a loss of control over the generator,
such as theft or vandalism. Reference (a) defines a radiological accident to be:

        (1) A loss of control of radioactive material which presents a hazard to
life, health or property or an event which may result in any member of the general
population exceeding limits for ionizing radiation.

        (2) Any unexpected event involving radioactive materials or radiation
exposure which prudence dictates to be of such consequence to warrant notification....
Included in this category are those events having domestic or international implications
and those which may give rise to inquiries by the public or press.

    d. **Types of Emergencies.** The three most credible types of emergencies
which could lead to a radiological accident as defined above are impact accidents, fires,
and loss of control over the generator.

    e. **Composition and Duration of an Emergency.** An emergency begins with
any event involving the RTG which potentially constitutes a radiological accident as de-
fined in paragraph 2.c above or which can be interpreted as loss of control over the
RTG. The emergency ends when any one of the following situations has been estab-
lished:

        (1) It has been determined by positive action that radioactive materials
have not been released.

        (2) If radioactive materials have been released, decontamination oper-
ations have been completed.

        (3) If control of the RTG has been lost:

            (a) Control has subsequently been regained, or

(b)   It has been determined that control cannot be regained at present and that this status is temporarily acceptable to competent authority.

f.   Emergency Actions and Procedures.   Emergency actions will be governed by the specific procedures set forth in this emergency plan; and in the event of a radiological accident by the instructions contained in reference (a).   Table 1 divides the emergency responses into chronological phases and provides general guidance as to the sequence of actions required for each emergency; detailed procedures are described in the remainder of this plan.

g.   Responsibilities.   In the event an emergency involving an RTG occurs, (enter the appropriate individual's title for each locations of use or storage) will be responsible for implementing the action required by this plan.

If it is subsequently determined that a radiological accident has occurred, reference (a) also applies.   This reference outlines actions which must be taken by the Primary Commander, Area Commander and Custodial Commander.   Should a radiological accident occur at _____ , the _____
_____ is the Primary Commander; the _____
_____ is the Area Commander; and the _____
_____ is the Custodial Commander.

(NOTE: Delineate responsibilities by title for each location of use or storage.)

h.   Notifications.   Emergency notifications will be made in accordance with paragraphs 9 and 10.

i.   Release of Information.   Release of information on radiological accidents is governed by referenced (a).

3.   General Aspects and Common Procedures for All Emergencies

a.   Emergency Protection Phase

(1)   Objective.   The objective of the emergency protection phase is to save human lives and to minimize potential or actual radiation exposures.

(2)   Duration.   The emergency protection phase begins with the discovery of the event which started the emergency and ends when the evacuation of humans from the emergency area has been completed.

(3)   Observe Radiation Precaution.   When in doubt that the radioactive material is still confined to its container, assume that the immediate accident area is radioactively contaminated and that anyone and anything in the ara MAY BE contaminated. Take special care to minimize personal contact with the outer clothing of individuals, the surface of the ground, vegetation, and the surfaces of other material within the accident area or material that has been removed from the acident area.

(4)   Rescue Humans.   Make every effort possible to rescue injured or trapped persons and remove them from the accident area.

(5)   Evacuate Humans.   Evacuate all persons from the emergency operations area to an assembly area where the radiation exposure under the circumstances could reasonably be expected to be zero or very nearly zero.

(a)   if any radioactive material has been released, and

(b)   if such material has been released, the extent of the contamination area, or

(c)   if such material has not been released, if there has been any loss of shielding.

(2)   Duration.   The situation determination phase begins as early as possible because information that radioactive materials have not been released will facilitate execution of the emergency protection and damage control phases and simplify some of the requirements in the preventive control phase. The situation determination phase ends when the actions indicated for that phase in Table 1 have been completed.

(3)   Conduct Radiological Surveys.   All monitors conducting the surveys will be equipped with pocket dosimeters and film badges or TLDs. (If abnormal radiation levels are encountered the monitor should not enter an area where the exposure rate exceeds 500 mrem/hr.) If the maximum exposure rate at the surface of the RTG is less than __*__ mrem/hr, it will be assumed that containment of the radioactive materials is intact, and the shielding has not been damaged; in this case a standard leak test of the RTG will be made. If the maximum exposure rate at the surface of the RTG is substantially greater than __*__ mrem/hr, it will be assumed that the shielding has been damaged. In this case a standard leak test of the RTG will be made so long as exposure rates greater than 500 mrem/hr are not encountered. If an exposure rate greater than 500 mR/hr is encountered, estimate the distance to the RTG from that point and check for contamination at that point.

* NOTE: Enter 1.2 times the normal maximum contact expsoure rate.

(4)   Notifications.   If shielding has been damaged or radioactive materials have been released, execute notification procedures (see paragraphs 9 and 10).

e.   Decontamination/Provisional Shielding Phase

(1)   Objective.   The objective of this phase is to provide provisional shielding and reduce contamination to acceptable levels.

(2)   Duration.   This phase begins with the emergency decontamination of humans, if required; otherwise with providing provisional shielding. The phase ends when radiation levels have been reduced to acceptable values and decontamination operations have been completed.

(3)   Decontaminate Humans.   If RTG surveys indicate exposure rates greater than 500 mR/hr or leak tests reveal the presence of contamination, individual(s) performing these tests or in the immediate vicinity of the RTG will be assumed to be contaiminated. Monitoring and decontamination (if required) of these personnel will be conducted in accordance with (reference or include appropriate procedures).

(4)   Provide Provisional Shielding.   Install temporary shielding materials to reduce exposure rates to acceptable levels. Make arrangements for permanent shielding and/or a suitable cask to remove the RTG from the accident site.

(5) **Develop Decontamination Plan.** The decontamination plan for equipment, facilities, and land areas will be developed.

(6) **Decontaminate Removable Equipment.** Equipment decontamination operations will be conducted in accordance with the plan developed under paragraph 3. e(5) above.

(7) **Decontaminate Facilities and Land Areas.** Facility and land area decontamination operations will be conducted in accordance with the plan developed under 3. e(5) above.

f. **Decontrol Phase**

(1) **Objective.** The objective of the decontrol phase is to eliminate controls as soon as such controls are no longer needed.

(2) **Duration.** The decontrol phase begins either as soon as it has been determined that radioactive materials have not been released and shielding has not been lost, or upon completion of the Decontamination Phase and/or establishment of provisional shielding. The decontrol phase ends when all controls over the movement of personnel and equipment have been released.

(3) **Announce End of Emergency.** The announcement at the incident site will be made in one of the following general forms, modified as required to fit the location situation:

(a) In the event that no radioactive materials have been released and no shielding has been lost; "Radioactive materials have not been released; the RTG is intact; the emergency phase is ended; the RTG will be handled in accordance with normal procedures."

(b) In the event that no radioactive materials have been released, but some shielding has been lost; "Radioactive materials have not been released; some shielding has been lost; the emergency phase is ended but radiation dose rates are higher than normal and special precautions will be required for handling the RTG."

(c) In the event that radioactive materials have been released: "Radioactive materials were released; decontamination operations have been completed; provisional shielding is in place; the emergency phase is ended but special handling procedures are required.

(4) **Release Control of Human Movement.** Permit persons to resume movement in the area subject to radiation safety regulations.

(5) **Release Control of Equipment Movement.** Permit equipment to resume movement in the area subject to radiation safety regulations.

(6) **Release Control of Area.** Remove special control points and eliminate special restricted areas. Retain normal radiation controls.

(7) **Release Supporting Forces.** Except for any security and radiation safety control required for the RTG, release special supporting force personnel.

(8)   Execute Notification Procedures

g.   Report Phase.   (Applicable only to radiological accidents.)

(1)   Objective.   The objective of the report phase is to provide a final official record of each radiological accident as required by reference (a).

(2)   Responsibility.   The final report as well as others required by reference (a) will be prepared by _____ .   Reports will contain all available essential elements of information providing a chronological history of the accident, information on what happened, what actions were taken in response thereto, the consequences of those actions, and the names and organizations of appropriate individuals involved.

(3)   Submit Final Report.   The completed report will be submitted as specified by reference (a).

4.   Actions and Procedures for Handling an Impact Accident

a.   Occurrence.   An impact accident could occur due to a mishap during handling of the RTG (loading, unloading, launching) or during transport of the RTG.

b.   Response to an impact accident will be as follows:

(1)   Execute emergency protection of human life.

(a)   Observe radiation precaution; see paragraph 3. a(3).

(b)   Rescue humans; see paragraph 3. a(4).

(c)   Evacuate humans; see paragraph 3. a(5).

(2)   Execute damage control measures.

(a)   Shut down equipment; see paragraph 3. b(3).

(b)   Contain damage; see paragraph 3. b(4).

(3)   Establish preventive control measures.

(a)   Establish control of human movement; see paragraph 3. c(3).

(b)   Establish control of equipment; see paragraph 3. c(4).

(c)   Establish control of area; see paragraph 3. c(5).

(4)   Determine actual hazard situation.

(a)   Conduct a radiological survey of the incident area; see paragraph 3. d(3).

(b)   If radioactive materials have not been released, and if there has been no loss of shielding, proceed to Decontrol Phase, paragraph 4. b(6).

(c) If radioactive materials have not been released, but there has been loss of shielding:

    1 execute notification procedures; see paragraphs 9 and 10.

    2 request assistance from _____.

    3 release preliminary information if necessary; see paragraph 2. i.

    4 provide provisional shielding, if necessary; see paragraph 3. e. (4).

    5 proceed to Decontrol Phase, paragraph 4. b(6)

(d) If radioactive materials have been released:

    1 execute notification procedures; see paragraphs 9 and 10.

    2 request assistance from _____.

    3 release preliminary information if necessary; see paragraph 2. i.

    4 proceed to Decontamination Phase, paragraph 4. b(5).

(5) Provide provisional shielding. Conduct decontamination operations.

(a) Decontaminate humans; see paragraph 3. e(3).

(b) Install provisional shielding, if required; see paragraph 3. e. (4).

(c) Develop a detailed decontamination plan; see paragraph 3. e. (5).

(d) Decontaminate removable equipment; see paragraph 3. e. (6).

(c) Decontaminate facilities; see paragraph 3. e. (7).

(6) End emergency and remove control measures.

(a) Announce end of emergency ; see paragraph 3. f(3).

(b) Release control of human movement; see paragraph 3. f(4).

(c) Release control of equipment movement; see paragraph 3. f(5).

(d) Release control of area; see paragraph 3. f(6).

(e) Release supporting forces; see paragraph 3. f(7).

(f) Execute notification procedures; see paragraphs 9 and 10.

(g) Release final information if necessary; see paragraph 2. i.

(7)   Prepare final report, if applicable.

   (a)   Write report; see paragraph 3. g(2).

   (b)   Submit report; see paragraph 3. g(3).

5.   Actions and Procedures for Handling a Fire Accident

   a.   Occurrence.   A fire accident could occur during transport of the RTG by any vehicle, or while the RTG is in storage or in a static position at an operational site.

   b.   Response to a fire accident will be as follows:

   (1)   Execute emergency protection of human life.

      (a)   Sound the alarm and inform the fire department that there is a fire involving an RTG. When emergency actions permit, notify local Safety personnel. Do not permit therse fire alarm actions to interfere with the rescue of jumans.

      (b)   Observe radiation precautions; see paragraph 3. a(3).

      (c)   Rescue humans; see paragraph 3. a(4).

      (d)   Evacuate humans; see paragraph 3. a(5).

   (2)   Execute damage control measures.

      (a)   Shut down equipment; see paragraph 3. b(3).

      (b)   Fight fire.   Fight the fire as though toxic chemicals are involved. To the extent possible keep upwind from the fire and avoid smoke, fumes, and dust. Segregate clothing and tools used at the fire until they can be checked for radioactive contamination before being returned to normal use. (This monitoring will not be necessary if radiological safety personnel determine that there has been no compromise of the RTG fuel containment.) Personnel involved in fire fighting operations shall wear pocket dosimeters or film badges/TLDs.

      (c)   Evacuate RTG and removable equipment.   If the fire is in the vicinity of the RTG, but does not involve the RTG, a reasobable effort shall be made to remove the RTG from the fire area at the earliest possible time without endangering personnel. If the fire has caused an increase in the ambient temperature in the vicinity of the RTG and the RTG has not suffered any visible externa' damage, the RTG should be kept cool with water spray, if possible. Evacuate other valuable equipment if fire conditions permit this action without endangering personnel.

      (d)   Contain damage; see paragraph 3. b(4).

   (3)   Establish preventive control measures.

      (a)   Establish control of human movement; see paragraph 3. c(3).

      (b)   Establish control of equipment movement; see paragraph 3. c(4).

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(c)   Establish control of area; see paragraph 3. C(5).

(4)   Determine actual hazard situation.

(a)   Conduct a radiological survey of the accident area; see paragraph 3. d(3).

(b)   If radioactive materials have not been released, and if there has been no loss of shielding, proceed to Decontrol Phase, paragraph 5. b(6).

(c)   If radioactive materials have not been released, but there has been loss of shielding:

1   execute notification procedures; see paragraphs 9 and 10.

2   request assistance from _____.

3   release preliminary information if necessary; see paragraph 2. i.

4   provide provisional shielding, if necessary; see . . . paragraph 3. e(4).

5   proceed to Decontrol Phase, paragraph 5. b(6).

(d)   If radioactive materials have been released:

1   execute notification procedures; see paragraphs 9 and 10.

2   request assistance from _____.

3   release preliminary information if necessary; see paragraph 2. i.

4   proceed to Decontamination Phase, paragraph 4. b(5).

(5)   Provide provisional shielding.   Conduct decontamination operations.

(a)   Decontaminate humans; see paragraph 3. e(3).

(b)   Install provisional shielding, if required; see paragraph 3. e(4).

(c)   Develop a detailed decontamination plan; see paragraph 3. e(5).

(d)   Decontaminate removable equipment; see paragraph 3. e(6).

(e)   Decontaminate facilities; see paragraph 3. e(7).

(6)   End emergency and remove control measures

(a)   Announce end of emergency; see paragraph 3. f(3).

(b)   Release control of human movement; see paragraph 3. f(4).

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(c)   Release control of equipment; see paragraph 3. f(5).

(d)   Release control of area; see paragraph 3. f(6).

(e)   Release supporting forces; see paragraph 3. f(7).

(f)   Execute notification procedures; see paragraphs 9 and 10.

(g)   Release final information if necessary; see paragraph 2. 1.

(7)   Prepare final report; if applicable

(a)   Write report; see paragraph 3. g(2).

(b)   Submit report; see paragraph 3. g(3).

6.   Actions and Procedures for Handling Loss of Control of an RTG (RTG Damaged)

    a.   Occurrence.   Loss of control resulting in a damaged RTG could occur due to vandalism and/or attempted theft at any time.

    b.   Response to loss of control resulting in a damaged RTG will be identical to the response for an impact accident; see paragraph 4. b.

7.   Actions and Procedures for Handling Loss of Control of an RTG (RTG Missing)

    a.   Occurrence.   Loss of control resulting in a missing RTG could occur due to attempted or actual theft at anytime or due to a mishap during transport.

    b.   Response to loss of control resulting in a missing RTG will be as follows:

        (1)   Determine present location of RTG. This may be accomplished by determining the last known geographical location of the RTG as accurately as possible, together with any information that may be helpful in predicting or determining the present location.

        (2)   If found, proceed as for an impact accident, see paragraph 4. b.

        (3)   If not found, proceed as follows:

            (a)   Execute notification procedures; see paragraphs 9 and 10.

            (b)   If necessary request assistance from _____.

            (c)   Release preliminary information if necessary; see paragraph 2. i.

8.   Actions and Procedures for Handling Loss of Control of an RTG (System Failure)

    (Describe here the actions which will be taken in the event of system failure or malfunction to insure that the RTG is intact and has not been tampered with. Include notification requirements. Applicable only when operation of the RTG/RTG powered system is monitored remotely. Disregard if this has been explained elsewhere in the application.)

9.   Local Notifications.   In the event any of the circumstances described in paragraphs 4 through 7 occur, notifications shall be made as outlined below.   Should the (enter name of RTG Powered System) fail, notifications will be made in accordance with paragraph 8.   (See paragraph 11 for CPREP-3 and Nuclear Regulatory Commission reporting requirements.)

      a.   For emergencies occuring at (enter location)_____,

            (1)   (Enter title or name)_____ , notify:

               (a)

               (b)

(A recall list should be established for each location of storage or use. This list should insure that appropriate personnel are contacted; for example: Radiation Protection Officer, primary RTG users, OOD/CDO, Commanding Officer, etc. Provide office and home phone numbers.)

10.   Notification of Higher Authority

      a.   Notifications made to report an emergency shall be made by voice insofar as possible unless precluded by security requirements.

      b.   Notification of the Nuclear Regulatory Commission may be required. Consult your license and 10 CFR 20.403 and 20.405 to make this determination.

      c.   References a) and b) require voice and message notification of USAF authorities in the event of certain incidents, including radiological accidents. (Complete this paragraph by listing specific USAF requirements for voice and message (OPREP) notifications. Cover both incidents and radiological accidents. Include telephone numbers and a sample message.)

APPENDIX C

PROCEDURE FOR MEASURING
EQUILIBRIUM
CURRENT - VOLTAGE DATA

APPENDIX C

PROCEDURE FOR MEASURING
"EQUILIBRIUM"
CURRENT - VOLTAGE DATA

1.0   <u>OBJECTIVE AND SCOPE</u>

1.1   <u>Objective</u>

The objective of this procedure is to establish steps for measuring stable RTG current and voltage.

1.2   <u>Scope</u>

This procedure is applicable to all Sentinel 25-series generators and the Sentinel 100F. The procedure assumes that two RTGs are tested simultaneously.

2.0   <u>REQUIREMENTS</u>

2.1   The following equipment is required to perform the tests specified herein.

2.1.1   RTG load box - P/N 014-50004-009.

2.1.2   RTG-PCU interconnecting cable assembly - P/N 014-50006-009, 014-50006-019, or 014-50006-029, as required.

2.1.3   Dana Digital Voltmeter - Model 5400,
                           or
     Keithley Digital Multimeter - Model 190 or equivalent.

3.0   <u>TEST SET-UP</u>

3.1   Get the load box (P/N 014-50004-009) and set both short circuit switches (S1 and S4) to the ON position.

3.1.1   If jumpers are connected between terminals 1 and 2, 3 and 4, 5 and 6, or 7 and 8 on Terminal Board 1, remove them.

3.1.2   Connect the shorting links on the side of the box between J7 and J8 and between J9 and J10.

3.1.3   Connect the MS connector on each of two RTG-PCU interconnecting cables to the load box, one to receptacle J1 and one to receptacle J2.

3.1.4   Remove the shorting plug from the first RTG and connect the mating cable end; repeat for the second RTG.

3.1.5   Document which RTG serial number is connected to J1 (Generator #1) and which serial number is connected to J2 (Generator #2).

3.1.6　　With jumper leads, connect terminals J3 and J4 to either a digital multi-
meter or digital voltmeter.

3.2　　Stable E-I Data

An RTG will be considered stable when all of the following conditions are
met:

a.　A minimum of three readings taken at consecutive one hour periods
have been recorded.

b.　A load voltage variation of less than 0.1 volt occurs in the two hour
time span.

If this condition is not met, continue to take readings at one hour intervals
until it is. Data should be taken only when an RTG is stable.

3.2.1　　Load voltage and load current are read directly from a digital meter with
the jacks plugged into the appropriate terminals. Current readings are
across a shunt with 50 amp/50 millivolt rating.

Open circuit voltage readings are obtained by plugging the meter jacks into
the load voltage terminals and holding the open circuit switch open for
approximately three seconds and recording the voltage value. A "hold"
feature on the meter is ideal for this purpose. As soon as the open circuit
switch is released it will return to its normally closed position.

3.2.2　　Completion of Tests

Repeat the steps in 3.2 for the following sequence of fixed loads: short
circuit, 0.1 ohm, 0.5 ohm and 1.1 ohm.

4.0　　DATA REQUIREMENTS

The following data should be recorded for each stable load point.

a.　Date and time.

b.　RTG Serial No.

c.　Load setting or short circuit.

d.　Load voltage - volts, DC. *

e.　Load current - amperes, DC. *

f.　Open circuit voltage - volts, DC.

* Obtain readings before open circuit.

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